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ENVIRONMENTAL BASELINE PROGRAM

NOVEMBER '74-
OCTOBER '76

FINAL REPORT

SYSTEM INTERRELATIONSHIPS

VOLUME 5

C-b SHALE OIL VENTURE • ASHLAND OIL, INC.
OCCIDENTAL OIL SHALE, INC., OPERATOR

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PROTOTYPE OIL SHALE LEASING PROGRAM

OIL SHALE TRACT C-b

ENVIRONMENTAL BASELINE PROGRAM

FINAL REPORT

(November 1974 Through October 1976)

VOLUME V

SYSTEM INTERRELATIONSHIPS

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Volume V of the Tract C-b final baseline report summarizes, integrates, and synthesizes much of the environmental information collected during the baseline study program. It also provides information enabling a user to find specific data in the earlier volumes. The six appendices to Volume V support and elaborate the development of the Tract C-b conceptual model. This volume approaches the description of major interrelationships on Tract C-b from a different perspective. Basically it uses a holistic approach of looking at the Tract as an environmental system divided in to many subsystems that interact. This approach permits the reader to use Volume V in at least six different ways. First, this volume summarizes a great deal of baseline information in nearly 500 times-series graphs that depict behavior of many components and processes in the ecosystem over a two-and-a-half year period. Secondly, this volume serves as a cross-reference to Volumes II, III, and IV by referencing the original data from which the time-series summaries were drawn. A third use of this volume, and perhaps the heart of it, is to examine the conceptual model of the Tract C-b system. Chapters 2 through 6 develop systematically this conceptual model. A fourth way to use the volume is to track environmental impacts using this conceptual model. System diagrams display the conceptual interrelationships in the terrestrial and aquatic portions of Tract C-b in such a way that a user can begin to understand the far-reaching ramifications of an impact on one part of that system as it is felt throughout the rest of the system. This type of information, of course, provides insights into planning a monitoring program, a fifth way to use this volume. Finally, in the same way, one can postulate environmental perturbations caused by man and, using the diagrams, determine how widespread the effects of these perturbations will be, and thus plan mitigation of these perturbations.

Chapter 2 focuses on ecosystem components in Tract C-b. Out of the plant and animal species that were identified and studied, and of the many environmental parameters that were monitored during the baseline program, Chapter 2 identifies key structural components of the ecosystem by aggregating and combining many of the individual things that were studied earlier. This aggregation is done to simplify analysis of the total system. For example, of the 14 plant community types that were identified during the baseline studies, five ecosystem response units are produced conceptually by aggregating some of the plant communities into one category based on similarity of vegetation and topography. These ecosystem response units are then related to the ecosystem components mentioned earlier so that the components are associated with particular ecosystem response units. The time-variant behavior of the many ecosystem components is discussed in detail in this chapter. This behavior was monitored during the baseline studies. In many cases, conceptually important components were not studied during the baseline period. However, estimates of the behavior of these components are also presented to round out the conceptualization.

Chapter 3 identifies 85 significant ecosystem processes that control the flow of matter and energy among the components of the ecosystem and among ecosystem response units. This chapter introduces the concept of flow currencies, i.e., the materials or the units of energy that actually flow between components. By establishing the linkages formed by flow currencies, and by identifying the processes that control these flows, Chapter 3 sets the stage for constructing a holistic conceptual model of the ecosystem.

The earlier chapters deal primarily with the Tract C-b environmental system as it existed during the baseline studies. Chapter 4 introduces the influences of oil shale development on the Tract. Using the engineering documents to determine the phases and activities associated with oil shale development, Chapter 4 identifies sources of environmental perturbations that may be anticipated during the development.

Chapter 5 synthesizes the materials from Chapters 2, 3, and 4 into a holistic view of the Tract C-b environmental system. The chapter identifies five flow currencies: heat, water, animal numbers, animal weights, and plant carbon. Each currency defines a separate subsystem. The animal numbers flow, then, constitutes one subsystem; the plant carbon flow another; etc. These subsystems are further linked spatially by flows among the ecosystem response units. The dynamics of the Tract C-b system are thus considered over both time and space. Superimposed upon the structure of the system as it existed during the baseline studies are the oil shale development influences. The complex interactions between the processes, the ecosystem components, and human influences are all documented in a series of figures that describe the factors affecting different flows in both the aquatic and terrestrial systems. Another set of figures concentrates on each flow individually as it is affected by different factors in the system. A very large matrix further focuses on these interrelationships, identifying the elements of the ecosystem that impinge upon various processes, with special consideration for potential influence of oil shale development on the system.

Chapter 6 carries the analysis further by developing total system diagrams that depict how the components and processes are linked together within the subsystems and how the subsystems themselves are linked within the aquatic and terrestrial systems. These large figures can be used as wall charts to trace environmental impacts and other effects throughout the system.

Chapter 7 utilizes the materials developed previously to identify and discuss major ecological interrelationships on Tract C-b. It discusses the abiotic-abiotic, the abiotic-biotic, and the biotic-biotic interactions of significant elements within the system. Of the more than 900 effects identified in the major matrix, Chapter 7 addresses 28 major effects anticipated from oil shale development. Only a few of the broad implications of these effects are discussed.

Chapter 8 develops ideas for utilization of Volume V in planning monitoring, and mitigation programs for the oil shale development. In addition, some suggestions are put forth for implementing numerically some portions of the conceptual model.

1.1 Introduction

Volume V of the Tract C-b final baseline report summarizes, integrates, and synthesizes much of the environmental information collected during the baseline study program. As such, it serves as an entry to specific data locations and discussions of the data in the preceding three volumes.

Any summary and synthesis of a large project is likely to be complex, and Volume V is no exception. To simplify this complexity and make the volume as useful as possible, it has been divided into three major components. The first, the main body of the volume, contains the results of the analyses and synthesis that have been necessary to characterize the Tract's system. Supporting and documenting the main text is the appendix component, which distills the essence of the baseline studies from the data reported in Volumes II, III, and IV. This distillation required organizing and sifting large quantities of data and other information, as documented in the appendices.

The third component of this volume is a User's Reference to Volume V. The User's Reference (also called Appendix F) is included in the supplementary envelope that accompanies this volume, along with several oversize foldouts. This reference contains alphabetized lists of all the ecosystem components and processes in the conceptual model described in the text; it also contains a glossary. Many of the words in the glossary are also underlined and defined the first time they appear in the text. The User's Reference is designed to refer the reader quickly to pertinent information. If used effectively, it should greatly assist readers in using Volume V.

1.2 The Approach

Volume V approaches description of major interrelationships on Tract C-b from a systems perspective. These interrelationships consist of innumerable feedback loops within and between the living and non-living portions of the system. This volume attempts to focus on major feedback loops as they operate on Tract C-b.

Because an environmental system contains living things interacting with both the non-living environment and each other, the entire system should be viewed in its entirety, rather than as a collection of unrelated objects. A systems perspective provides a new way of looking at the environmental system. More specifically, it is a way of organizing environmental data and information about the system somewhat more formally and systematically than has usually been done in the past. It is this approach that is used in Volume V.

Institution of such an organizational framework automatically produces a model of the ecosystem. A model is merely an abstraction that tries to capture the essential portions of a system in less detail than would be required to reconstruct the entire system. For example, simple verbal descriptions of ecological interactions are models--in this case, word models. Topographic maps are models. Matrices and box-and-arrow diagrams, such as appear in Volume V, are also models. Mathematical equations and the computer programs to solve them are forms of more complex models.

A systems approach exploits the organizational power associated with different types of model building to array, analyze, and synthesize environmental data and information so we can improve our understanding of the ecosystem and our ability to predict what will happen to that system if it is stressed by human-controlled or natural influences.

By using a systems orientation, Volume V organizes data and information from the preceding volumes into a qualitative model from which we can begin (1) to understand the functioning of the C-b Tract ecosystems and (2) to identify ecosystem components and processes that are important to monitor.

1.3 The Tract C-b System

The area of proposed oil shale development can be viewed as a living system interacting with its environment and composed of component subsystems, each interacting with every other and with other factors in the environment. To understand the anticipated effects of development on Tract C-b we must first understand the environmental system as it exists now; then we must superimpose intellectually on that system the expected disturbances brought to the system by development of the oil shale resources.

1.3.1 What is a System?

As the term is used here, a system is a collection of objects which, by their interaction and interdependence, form an entirety that functions in a particular way. Often components of that entirety interact to confer on the system certain emergent properties that might not readily be inferred from a study of the component parts separately; first-, second-, and higher-order interactions between and among components cause the system to behave uniquely as a functional unit rather than as the simple sum of all the component activities. In other words, because of synergistic effects, the system takes on behavioral characteristics that transcend the characteristics of its component parts.

Structural components of a system are called variables, because they vary through time and space. Usually variables are of two types: driving variables and state variables. Driving variables provide input to the system from outside; in a sense, they "drive" the system. These components are external to the system in that they affect the ecosystem without themselves being affected by it. Components that influence each other through abiotic or biotic feedback are called state variables. These components are within the system, and they interact with each other sufficiently to affect each other's behavior.

In living systems, variables are linked to each other by flows of matter or energy, and they interact with each other through these flows. Certain system processes act as valves to regulate the flows: as the rate of a process changes, the flow rate changes, and the state variable dependent on that flow is affected. Processes are regulated by driving variables and, often through feedback, by state variables.

1.3.2 The Ecosystem

In ecology, a "system" may be an organism, a species population, or a total ecosystem. This volume deals with a complex of ecosystems that make up Tract C-b and its immediate vicinity. The ecosystems on Tract C-b are more or less naturally evolved collections of living things interacting with each other and with their non-living environment to form recognizable units characterized by unique emergent properties.

In an ecosystem, driving variables are usually natural abiotic components. Examples are insolation or precipitation. However, they also include certain man-influenced inputs, such as pesticides, herbicides, grazing management, or influences deriving from activities such as oil shale development. State variables are components grouped in such a way as to describe the ecosystem of interest as economically as possible. A state variable could be a single species of plant, a life form (grass, forb, shrub, tree, etc.), or even all plants in the system. Selection of state variables depends on the level of resolution at which we want to describe the system and on the importance of each component.

Common processes in ecosystems are photosynthesis, respiration, birth, death, etc. These example processes control the flow of carbon through the system. Other processes regulate other flows.

1.3.3 The Tract C-b Environmental System

During the period of baseline study, 14 distinct plant communities were identified on the Tract. Because of certain similarities, some of these were aggregated for simplicity into ecosystem response units. An ecosystem response unit is a geographical, or spatial, unit that (1) possesses common vegetative, topographic, elevational, and edaphic, (or aquatic) characteristics, and (2) responds to environmental influences more or less uniformly throughout.

Response units on Tract C-b were chosen for their relative homogeneity at the level of resolution considered here. The vegetative types were grouped into five ecosystem response units: upland forest, general upland, general bottomland, meadow, and aquatic. Effectively, response units are considered to be small ecosystems within the larger environmental system of the entire Tract area.

Upon this natural environmental system, two additional ecosystem response units will be imposed by oil shale development: upland rehabilitated sites, and bottomland rehabilitated sites.

In addition to the natural driving variables of the system (precipitation, air temperature, wind, and solar radiation), many of man's influences will drive the system as well. These include forest cutting, livestock grazing, in addition to the possibility of certain emissions and other disturbances attributable to oil shale development. How these might affect the environmental system can be inferred from the conceptual model developed in this volume.

1.4 Qualitative Analysis of the System

1.4.1 Qualitative versus Quantitative

The approach taken in the following sections is largely qualitative. It presents box-and-arrow diagrams, matrices, and verbal descriptions of the important environmental interrelationships that exist on the Tract. These conceptualizations are qualitative in that they describe the behavior of ecosystem components and processes in terms of their qualities. This is always an early necessary step toward more rigorous analysis.

Quantitative analysis of the ecosystems as systems is beyond the immediate needs of the final baseline report. It would require building mathematical equations that describe the ecosystem dynamics, determining numerical values of the parameters for those equations through extensive statistical correlation techniques and literature search, and building a computer simulation model to study the dynamics of the Tract C-b environmental system.

Many different types of data were analyzed numerically in Volumes II, III, and IV, but there was virtually no attempt to cross-correlate data on the different ecosystem variables that were measured. The conceptual model developed below draws qualitative inferences from those data as well as from other ecological sources and principles outside the baseline study.

1.4.2 Interpreting Baseline Information

Interpretation of the baseline data and information of earlier volumes was governed by simple modeling criteria: to identify and describe interrelationships within the Tract's environmental system it was necessary to systematically organize an extremely large data base in order to minimize loss of information, and to rationally reduce that data base to a workable size.

To build the model, it was first necessary to identify all the state and driving variables that might be important. For Tract C-b this required reviewing and re-organizing species lists and vegetative communities into functional components at a medium level of resolution. (The level of resolution is the degree to which component parts are combined or separated, hence, the amount of detail presented.) This time-consuming process required interactive consultations with disciplinary specialists to determine which species could be aggregated into which groups in a reasonable way.

Simultaneously, the flows that link the variables were identified. The model here uses carbon, animal numbers, animal weights, water, heat, and land area as environmental currencies that flow between the various subsystems. After the flow currencies and components were chosen, the processes that control the flows were identified and similarly aggregated or separated according to their importance within the level of resolution specified. The choice of these was constrained by the baseline information available and by considerations for future monitoring.

1.5 Uses of Volume V

Volume V can be used in at least six different ways: (1) it summarizes baseline information; (2) it cross-references much of the data in Volumes II, III, and IV; (3) it provides a conceptual model of the C-b Tract; (4) it can be used to track environmental impacts through the Tract ecosystems; (5) it provides information that can be used to design a monitoring program; and (6) it provides information useful for planning a mitigation program.

This volume summarizes a great deal of baseline information in nearly 500 times-series graphs that depict behavior of many components and processes in the ecosystem over a two-and-a-half year period. This volume also serves as a cross-reference to Volumes II, III, and IV, by referencing the original data from which the time-series summaries were drawn. A third use of this volume, and perhaps the heart of it, is to examine the conceptual model of the Tract C-b system. Chapters 2 through 6 develop systematically this conceptual model. A fourth way to use the volume is to track environmental impacts using this conceptual model. System diagrams display the conceptual interrelationships in the terrestrial and aquatic portions of Tract C-b in such a way that a user can begin to understand the far-reaching ramifications of an impact on one part of that system as it is felt throughout the rest of the system. This type of information, of course, provides insights into planning a monitoring program, a fifth way to use this volume. Finally, in the same way, one can postulate environmental perturbations caused by man and, using the diagrams, determine how widespread the effects of these perturbations will be, and thus plan mitigation of these perturbations.

2 ECOSYSTEM COMPONENTS

2.1 Introduction

This chapter reviews the structural components that were studied in the Tract C-b environmental system and reduces the number of components to a workable size. Before important components could be identified and chosen for subsequent discussion from among innumerable driving and state variables, some selection criteria had to be developed. Choice of driving variables and abiotic state variables (e.g., soil moisture) was governed by the importance of these variables in influencing processes and flows in the Tract system. Importance was determined by the emphasis placed on these variables in the baseline studies and through discussions with the principal investigators for the various disciplines. In selecting component categories for the biotic state variables, the variables were grouped according to functional role in the system, i.e., trophic level, life form, etc. The objective was to include 90 to 95 percent of any trophic group within the component categories. The specific rationale and the evolutionary process of defining ecosystem components is documented in Appendix A.

2.2 Structural Components--Flora, Fauna, and Abiotic

One of the most important criteria to be specified is the level, or levels, of resolution at which the system is examined. Selection of a workable level requires trade-offs between too little and too much detail.

The ecosystem components are described at different levels of resolution. In the simple model developed for Tract C-b systems, the lowest level aggregates components into four natural driving variables, 11 man-induced driving variables, and 25 state variables. Many of the state variables, however, are easily disaggregated into several subdivisions. The state variable "terrestrial animals," for example, can be disaggregated into 10 functional categories in most ecosystem response units: cattle; deer; insectivorous, omnivorous, and carnivorous birds; predatory mammals; rabbits; rodents; reptiles; and arthropods. Through a system of subscripts, these state variables are easily expanded to the higher degree of resolution if such expansion becomes necessary to examine a particular component or subsystem in more detail.

Early lists of structural components of the Tract C-b ecosystems appeared in the Annual Summary and Trends Report (C-b1976b), which summarized results of baseline studies conducted in 1975. These were modified to include components added during subsequent studies. Appendix A contains the total list of some 425 ecosystem components considered significant on the Tract C-b study area. Such a comprehensive list permits careful scrutiny of anything within the natural ecosystem that might possibly be affected by man-induced changes in the system. Effectively, it is simply an inventory. This inventory provides a point of departure for further aggregation. Components in the listing are grouped according to their functional roles in the ecosystem.

From the comprehensive inventory list given in Appendix A, a reasonable number of driving and state variables (Tables 2-1 and 2-2) were aggregated, consistent with the degree of resolution chosen. Many state variables are followed by subscripts that further subdivide these aggregations for a higher degree of resolution. These subscripts are explained in Section 2.4, after the units to which they refer are discussed.

2.3 Spatial Units

Fourteen plant communities/habitat types were identified in the Tract C-b study area, as described in the Annual Summary and Trends Report (C-b 1976b, pages 299-359). One type, the Douglas-fir community, has been omitted from discussion because of its extremely limited occurrence in the area. The 13 remaining types were aggregated into five ecosystem response units primarily on the basis of common vegetative physiognomies and topographic locations (Table 2-3). The vegetation, of course, provides an excellent link between the abiotic components and the animals. When integrated into plant-animal-topographic response units, these functional spatial units can be viewed conceptually as small ecosystems that constitute the larger environmental system of the entire Tract.

Two types of upland systems, two types of bottomland systems, and an aquatic system are identified. Upland areas are subdivided into forested and non-forested (general upland) categories. All bottomland vegetation types except the meadows have been combined. Meadows are treated separately because, although they make up a very small component of the Tract C-b system, the dynamics and importance of this component are disproportionate to its size. Similarly, streams, ponds, and marshes make up only a small proportion of the surface acreage of the Tract C-b system, but these are important habitats. It is anticipated that oil shale development will dramatically change certain portions of some of these response units and will replace them. Thus, two additional response units associated with oil shale development have been included for

Table 2-1

IMPORTANT DRIVING VARIABLES IDENTIFIED ON TRACT C-b. THE INITIAL D IN THE ACRONYMS IDENTIFIES THE VARIABLES AS DRIVING VARIABLES.

TYPE OF VARIABLE	DRIVING VARIABLE NAME	ACRONYM
CLIMATIC	precipitation	DPT
	air temperature	DTA
	wind	DWD
	solar radiation	DRD
RESOURCE MANAGEMENT	forest cutting schedule	DCT
	livestock grazing schedule	DGR
OIL SHALE DEVELOPMENT	sulfur compound emissions	DOL (1)
	nitrogenous compound emissions	DOL (2)
	ozone and oxidant emissions	DOL (3)
	trace metal contaminants	DOL (4)
	carbon monoxide emissions	DOL (5)
	water vapor emission	DOL (6)
	fugitive dust	DOL (7)
	noise and activity disturbance	DOL (8)
	secondary hunting and recreation	DOL (9)

Table 2-2

IMPORTANT STATE VARIABLES IDENTIFIED ON TRACT C-b. THE INITIAL LETTER OF EACH ACRONYM REFERS TO THE FLOW CURRENCY OF THE SUBSYSTEM IN WHICH THAT VARIABLE APPEARS. SUBSCRIPTS ARE EXPLAINED IN SECTION 2.4.

SUBSYSTEM TITLE AND ABBREVIATION	AGGREGATE STATE VARIABLE NAME	ACRONYM	LIMIT	
			I	J
ANIMAL POPULATION (P)		(P=Population)		
	source	PSS		
	terrestrial animal numbers	PTA (I,J)	10	10
	aquatic vertebrate numbers	PAV (I)	2	
	aquatic invertebrate numbers	PAI (I)	2	
	sink	PSS		
ANIMAL WEIGHT (K, for kilograms)		(G=Grams)		
	source	GSS		
	terrestrial animal weights	GTA (I,J)	10	10
	aquatic vertebrate weights	GAV (I)	2	
	aquatic invertebrate weights	GAI (I)	2	
	sink	GSS		
CARBON BIOMASS (C)	source	CSS		
	live shoots	CVS (I,J)	10	5
	live roots	CVR (I,J)	10	5
	standing dead	CVD (I,J)	10	5
	aboveground litter	CLA (I)	10	
	belowground litter	CLB (I)	10	
	aquatic rooted plants	CAR (I)	2	
	aquatic nonrooted plants	CAN (I)	2	
	aquatic detritus	CAD (I)	2	
	sink	CSS		
HEAT (H)	source	HSS		
	soil top layer heat	HST (I)	10	
	soil bottom layer heat	HSB (I)	10	
	aquatic top layer heat	HAT (I)	2	
	aquatic bottom layer heat	HAB (I)	2	
	sink	HSS		
WATER (W)	source	WSS		
	surface water (snow, ice, rain)	WSI (I)	10	
	top soil water	WTS (I)	10	
	bottom soil water	WBS (I)	10	
	ground water layer	WGR (I)	10	
	aquatic ice layer water	WAI (I)	2	
	aquatic water	WAW (I)	2	
	sink	WSS		
ACREAGE	surface area	ACR (I)	12	

future projections: upland rehabilitated and bottomland rehabilitated sites.

2.4 Identifying and Relating Ecosystem Components and Response Units

Table 2-2 contains two columns designating "subscript limits." The numbers in these columns refer to two different groupings. Subscript I identifies the ecosystem response unit in which the state variable is found (Table 2-3), and subscript J identifies the disaggregated categories into which some state variables can be separated (Table 2-4). By using this system of subscript notation, we can designate which variables, and which of their subdivisions, are found in a particular ecosystem response unit. Although subscripts are handy for computerization, they can sometimes be confusing; thus, a system of acronyms is used for the disaggregated variables in this volume, except for oil shale variables, which are simply numbered 1 through 9. Driving variables are denoted by an initial "D," followed by two other letters that symbolize the variable (Table 2-1). All oil shale development variables are spelled "DOL," followed by subscripts 1 through 9.

All aggregated state variables are denoted by three letters. The initial letter indicates the material or energy that flows through that state variable; it thus also specifies the particular subsystem of which that variable is a part. For instance, all plant state variables are in the carbon flow subsystem, so the initial which identifies plants is "C." These abbreviations are listed in Table 2-2.

For state variables that have subscripts, one or two additional letters have been added to the basic acronym of the aggregated state variable to produce a four- or five-letter acronym for each disaggregated subdivision. For example, the aggregated variable called "terrestrial animal numbers" is denoted by "PTA." This classification, however, is also subdivided into 10 animal state variables (Table 2-2). One of these subdivisions is cattle, which is denoted by PTAC. The deer state variable is PTAD, rabbits are PTARA, rodents are PTARO, etc. The expanded list of variables and their acronyms is found in Tables 2-5 and 2-6. The User's Reference (Appendix F) is included in the supplementary envelope that accompanies this volume along with a complete list of variables and their acronyms, alphabetized for easy reference.

2.5 Time-series Dynamics of Components

One form of model that is widely used in a variety of analyses is a simple line graph showing the changing behavior of some

Table 2-3

AGGREGATIONS OF PLANT COMMUNITIES INTO ECOSYSTEM RESPONSE UNITS FOR A CONCEPTUAL MODEL OF THE C-b SYSTEM

PLANT COMMUNITY/ HABITAT TYPE	ECOSYSTEM RESPONSE UNITS	SUBSCRIPT I
PINYON-JUNIPER	UPLAND FOREST	1
CHAINED RANGELAND BUNCHGRASS SAGEBRUSH MOUNTAIN SHRUB	GENERAL UPLAND	2
RABBITBRUSH GREASEWOOD SAGEBRUSH WILDRYE RIPARIAN	GENERAL BOTTOMLAND	3
MEADOW	MEADOW	4
STREAM POND/MARSH	AQUATIC	5
	UPLAND REHABILITATED	6
	BOTTOMLAND REHABILITATED	7

Table 2-4

SUBDIVISIONS OF STATE VARIABLES USED IN THE CONCEPTUAL MODEL, WITH SUBSCRIPTS

AGGREGATED STATE VARIABLE	SUBSCRIPT J	DISAGGREGATED VARIABLE
	1	Cattle
	2	Deer
	3	Insectivorous birds
Terrestrial animals numbers -- PTA(I,J)	4	Omnivorous birds
	5	Carnivorous birds
Terrestrial animal weights -- GTA(I,J)	6	Mammalian predators
	7	Rabbits
	8	Rodents
	9	Reptiles
	10	Arthropods
	1	Annual plants
Live shoots -- CVS(I,J)	2	Perennial grasses
Live roots -- CVR(I,J)	3	Perennial forbs*
Standing dead -- CVD(I,J)	4	Shrubs
	5	Trees

* Category 3 is also used to summarize herbaceous shoots in Figure 3.5 and standing dead in Figure 3.6 because measurements on herbaceous biomass did not differentiate between annuals and perennials.

Table 2-5

EXPANDED LIST OF DRIVING VARIABLES AND THEIR ACRONYMS

Number	Variable Name	Acronym
1	Precipitation	DPT
2	Air Temperature	DTA
3	Wind	DWD
4	Solar Radiation	DRD
5	Forest Cutting Schedule	DCT
6	Cattle Grazing Schedule	DGR
7	Sulfur Compound Emissions	DOL (1)
8	Nitrogen Compound Emissions	DOL (2)
9	Ozone and Oxidant Emissions	DOL (3)
10	Trace Metal Emissions	DOL (4)
11	Carbon Monoxide Emissions	DOL (5)
12	Water Vapor Emissions	DOL (6)
13	Fugitive Dust	DOL (7)
14	Noise and Activity Disturbance	DOL (8)
15	Secondary Hunting and Recreation	DOL (9)
16	Humidity	DHU
17	Barometric Pressure	DBP

Table 2-6

EXPANDED LIST OF STATE VARIABLES AND THEIR ACRONYMS

Number	Variable Name	Acronym
1	Cattle Numbers	PTAC
2	Deer Numbers	PTAD
3	Insectivorous Bird Numbers	PTABI
4	Omnivorous Bird Numbers	PTABO
5	Carnivorous Bird Numbers	PTABC
6	Coyote & Bobcat Numbers	PTACB
7	Rabbit Numbers	PTARA
8	Rodent Numbers	PTARO
9	Reptile Numbers	PTARE
10	Arthropod Numbers	PTAAR
11	Individual Cattle Weights	GTAC
12	Individual Deer Weights	GTAD
13	Individual Insectivorous Bird Weights	GTABI
14	Individual Omnivorous Bird Weights	GTABO
15	Individual Carnivorous Bird Weights	GTABC
16	Individual Coyote & Bobcat Weights	GTACB
17	Individual Rabbit Weights	GTARA

Table 2-6

(CONTINUED)

Number	Variable Name	Acronym
18	Individual Rodents Weights	GTARO
19	Individual Reptile Weights	GTARE
20	Individual Arthropod Weights	GTAAR
21	Live Shoots Annual	CVSAN
22	Live Shoots Perennial Grass	CVSGP
23	Live Shoots Perennial Forb	CVSFP
24	Live Shoots Shrub	CVSSH
25	Live Shoots Tree	CVSTR
26	Standing Dead Annual	CVDAN
27	Standing Dead Perennial Grass	CVDGP
28	Standing Dead Perennial Forb	CVDFP
29	Standing Dead Shrub	CVDSH
30	Standing Dead Tree	CVDTR
31	Live Roots Annual	CVRAN
32	Live Roots Perennial Grass	CVRGP
33	Live Roots Perennial Forb	CVRFP

Table 2-6

(CONTINUED)

Number	Variable Name	Acronym
34	Live Roots Shrub	CVRSH
35	Live Roots Tree	CVRTR
36	Aboveground Litter	CLA
37	Belowground Litter	CLB
38	Upper Soil Layer Temperature	HST
39	Lower Soil Layer Temperature	HSB
40	Surface Water (Snow)	WSI
41	Upper Soil Layer Water	WTS
42	Lower Soil Layer Water	WBS
43	Ground Water	WGR
44	Terrestrial Land Areas	ACRT
45	Aquatic Vertebrate Numbers	PAV
46	Aquatic Invertebrate Numbers	PAI
47	Individual Vertebrate Weights	GAV
48	Individual Invertebrate Weights	GAI
49	Rooted Biomass Plants	CAR
50	Non-rooted Biomass Plants	CAN

Table 2-6

(CONTINUED)

Number	Variable Name	Acronym
51	Detritus Biomass	CAD
52	Upper Water Layer (ice) Temperature	HAT
53	Lower Water Layer (water) Temperature	HAB
54	Upper Water Layer Volume	WAI
55	Lower Water Layer Volume	WAW
56	Surface Area of Aquatic Types	ACRA

variable plotted against time. This type of time-series analysis is extremely useful for understanding how components of the ecosystem behave throughout the year and vary from year to year. Many of the individual baseline studies conducted on Tract C-b were concerned with this phenomenon; nearly 500 driving variables, state variables, and ecosystem flow rates from the actual data of these studies have been summarized in Appendix B on a uniform time scale. Each is cross-referenced in the User's Reference (Appendix F) to the original graph or table appearing in Volumes II, III, or IV of this final report.

An early step in trying to understand time-variant behavior is to develop such plots. The next step is to try to discover cause-effect relationships that produce a particular time-varying pattern. In this volume we have summarized the annual behavior of state and driving variables and then have attempted to identify some of the factors controlling that behavior.

About two-thirds of the time-series graphs in Appendix B are relevant to the state and driving variables of our conceptual model. These were used to develop a general, annual time-series curve for each pertinent variable of the model. Where more than one graph was available, as in the case where several stations recorded annual precipitation, the general annual curve was drawn by tracing each separate graph on the same sheet of paper to form a composite curve from the several locations. For each variable, a single curve was then visually estimated from this composite. Where no data were collected, annual behavior of a given variable was estimated by dashed curves. These graphs appear in a series of figures along with accompanying textual explanations as follows:

2.5.1 Precipitation

Averaging the precipitation records obtained in portions of 1974, 1975, and 1976 at several different locations on the Tract gives the impression noted in Figure 2-1-DPT. Averaged over all locations, maximum precipitation rates are about 4 cm in June and July. Minimum precipitation appears to be less than 1 cm in September and October. The first two-thirds of the year contribute most of the precipitation.

2.5.2 Air Temperature

Air temperature values peak in July (Figure 2-1-DTA). Minimal values are in the December to January interval. Air temperature patterns show greater dynamics than do solar radiation and a lag with respect to peak times. The buildup and decrease of air temperature before and after the peak air temperature is approximately symmetrical.

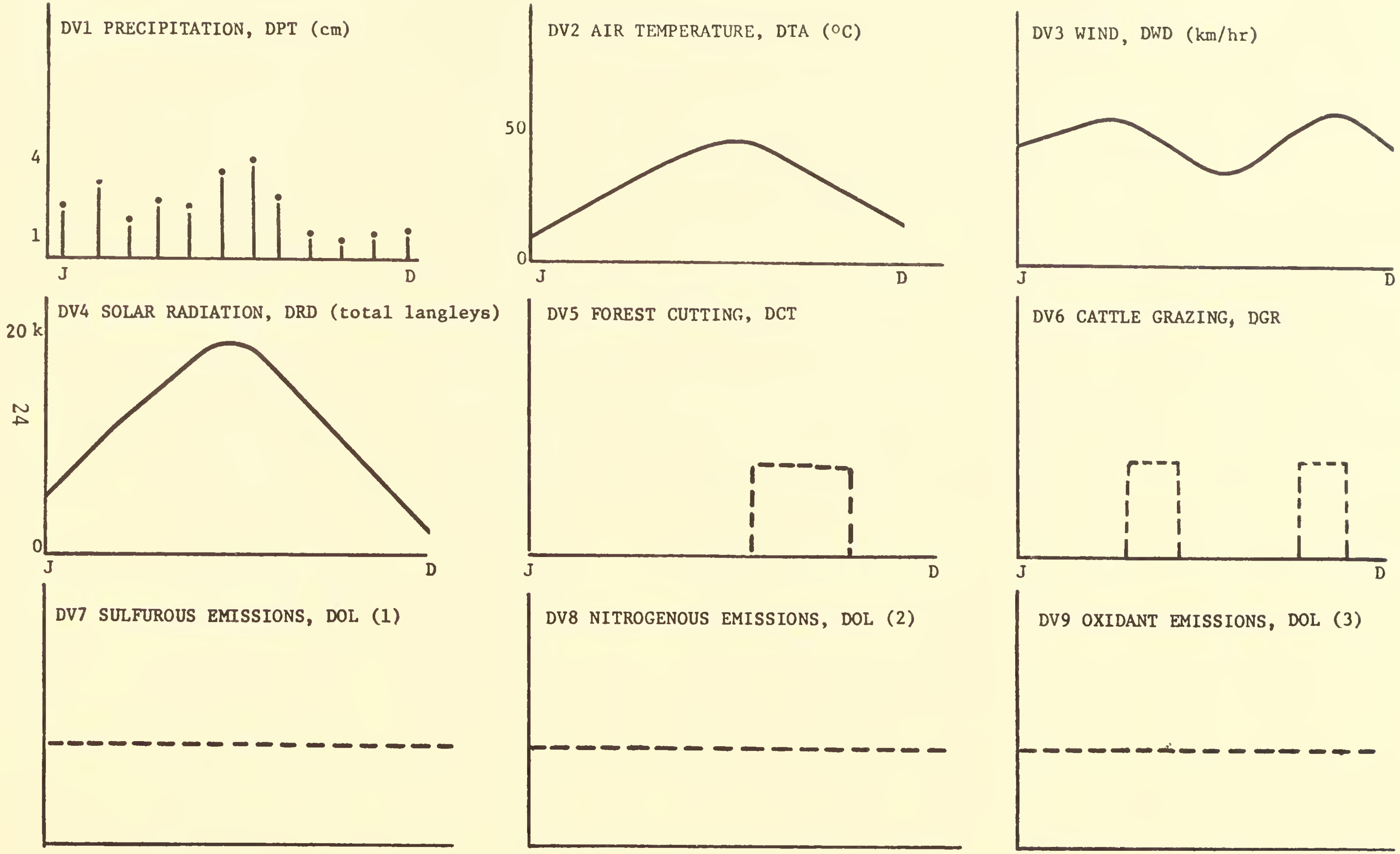

Figure 2-1 SIMPLIFIED DYNAMICS OF THE DRIVING VARIABLES OF THE TRACT C-b SYSTEM CONCEPTUAL MODEL BASED ON 1974-1976 MEASUREMENTS AND ESTIMATES. VARIABLE NUMBERS AND ACRONYMS ARE THOSE IN TABLE 2-5. SOLID-LINE GRAPHS ARE BASED ON ACTUAL DATA COLLECTED FROM THE TRACT C-b SYSTEM: DOTTED-LINE GRAPHS ARE BASED ONLY ON ESTIMATES. VARIABLE ACTIVITY IN EACH CASE IS SHOWN FOR A ONE-YEAR PERIOD FROM JANUARY (J) THROUGH DECEMBER (D).

2.5.3 Wind

A summary of wind measurements in 1974 through 1976 is illustrated in Figure 2-1-DWD. Two peak periods of high wind velocity occurred during the year, the first in early April and the second in the October-November interval. Minimal wind velocities occurred in July.

2.5.4 Solar Radiation

The summary of solar radiation data shows a peak in the June-to-July interval with maximal values about five times greater than minimal values. The minimal values are in the December to January interval (Figure 2-1-DRD). The buildup and decrease of solar radiation input between minimum and maximum is uniform. In contrast to air temperature values, whose maximal values were only about twice the minimum mean monthly values, there is more variation in solar radiation.

2.5.5 Resource Management Driving Variables

Two types of renewable resource management practices have been in effect on Tract system, i.e., the cutting of the pinyon-juniper upland forests and grazing by domestic livestock. These are shown in Figure 2-1-DCT and Figure 2-1-DGR. Forest cutting is included as a driving variable in the conceptual model because of the possibility of harvest of the pinyon-juniper woodland in preparing sites for disposal areas of spent shale or stored shale. It is presumed that forest cutting would occur from August until late fall: Because soils would be dry at this time, the area would be accessible , and most of the plants would be mature, less damage would be caused by cutting at this time. Cattle graze through the Tract area both in the spring on the way to higher elevations and in the fall on the return to the meadowlands for the winter (Figure 2-1-DGR). The numbers are approximately the same in both spring and fall.

2.5.6 Oil Shale Development-Related Driving Variables

Several effluents may be expected from an in situ oil shale development process. These are discussed in a later section, but for present purposes it can be assumed that the emission rates will be relatively constant over the year. Thus sulfurous, nitrogenous, oxidant, trace metal, and carbon monoxide emissions are uniform over the year [(Figure 2-1-DOL(1), DOL(2), and DOL(3); Figure 2-2-DOL(4) and DOL(5).] The levels are yet to be established. For other oil shale development-related driving variables, however, the driving variable values can be expected to vary during the year. For instance, water vapor could be expected to have less effect in the summer, when temperatures are high and relative

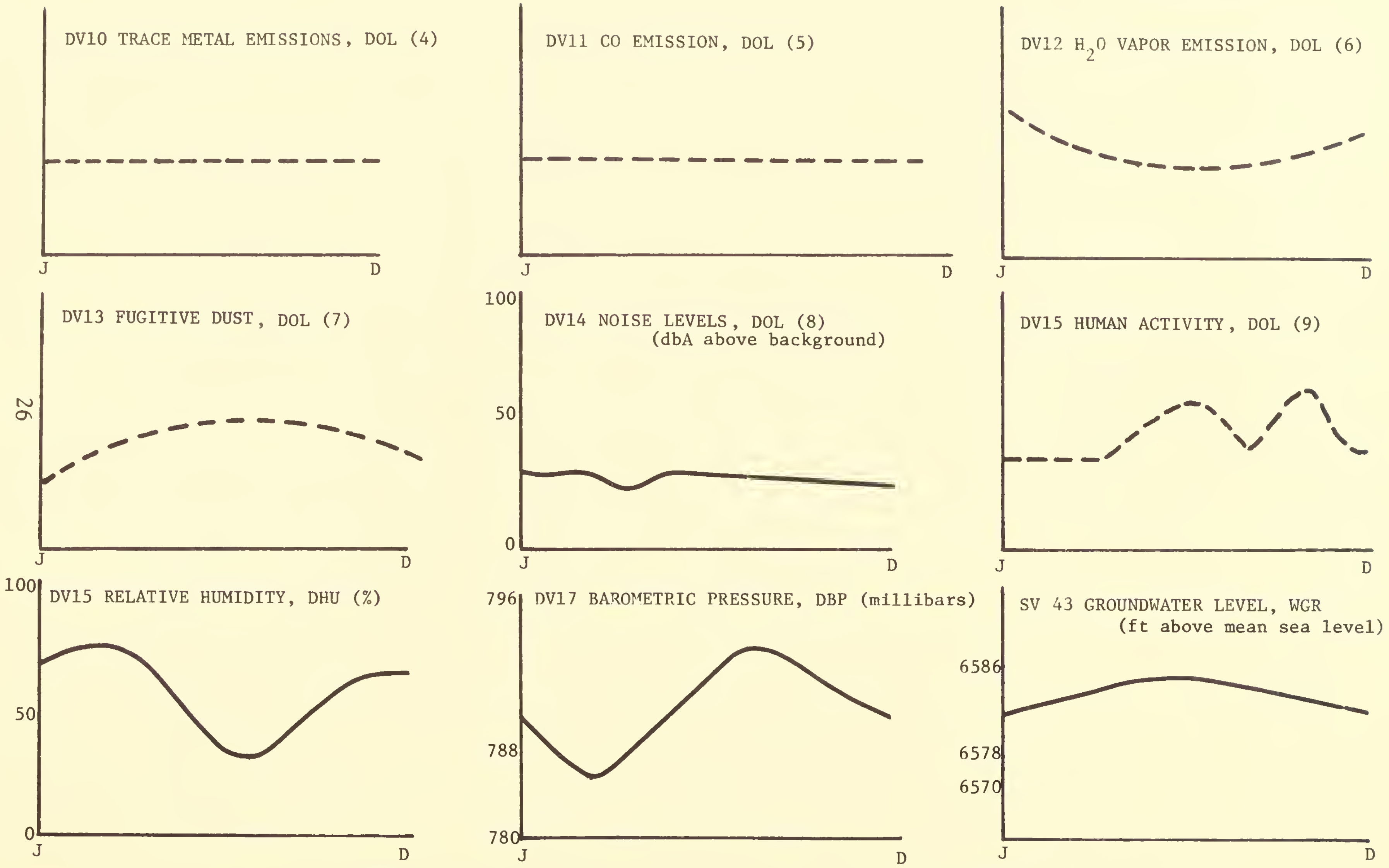

Figure 2-2 SIMPLIFIED DYNAMICS OF VARIABLES ON THE TRACT C-b SYSTEM CONCEPTUAL MODEL BASED ON 1974-1976 MEASUREMENTS AND ESTIMATES. LEGEND IS THE SAME AS IN FIGURE 2-1.

humidity is low, than in the winter, when temperatures are low and relative humidity is higher [Figure 2-2-DOL(6)]. Fugitive dust from shale mining operations, from storage and transport, and from surface activities could be expected to be higher in late summer and early autumn than at other periods during the year [Figure 2-2-DOL(7)].

Prior to development, background noise levels showed relatively uniform values throughout the year except for an unexplainable low in early spring. Noise levels after oil shale development could be expected to be approximately constant except for increase in noise related to forest cutting practices relative to development; such cutting would occur in late summer-early autumn. Average values for measured noise levels are illustrated in Figure 2-2-DOL(8).

The oil shale development process will have a greatly increased human activity level related to movements of men and material than is present now on the Tract. A secondary influence will be hunting and recreational activities brought about by increased population. When the base human activity is combined with hunting and recreational activities, it is estimated there will be activity peaks in summer and in autumn [Figure 2-2-DOL(9).] Relatively low levels of human activity will occur in late summer-early autumn and also during winter and most of the spring.

Other variables have been measured which are not in the driving variable list given above. These represent important proxy variables that could be considered to be driving or state variables in further conceptualization. These are summarized at the bottom of Figure 2-2. Relative humidity averages as low as 30% in the month of July and as high as about 75% in late winter-early spring. Barometric pressure, as measured in 1974 through 1976, has lowest values in March and highest values in August. Depth of water has been measured in a series of wells. Groundwater is later utilized as a state variable, but in some conceptualizations groundwater might be considered a driving variable. Despite wide variation among individual wells, higher groundwater levels are generally found in April through June than at other times in the year, while the lowest groundwater levels are found in the winter.

Most of the time-series measurements made in the baseline studies on the Tract are for state variables. These state variable dynamics are discussed in the following sections.

2.5.7 Animal Numbers

When they are in the system, cattle are considered a state variable. Their number builds to a peak and then drops off each spring and fall (Figure 2-3-PTAC). There are approximately equal maximum numbers present in the spring and the fall.

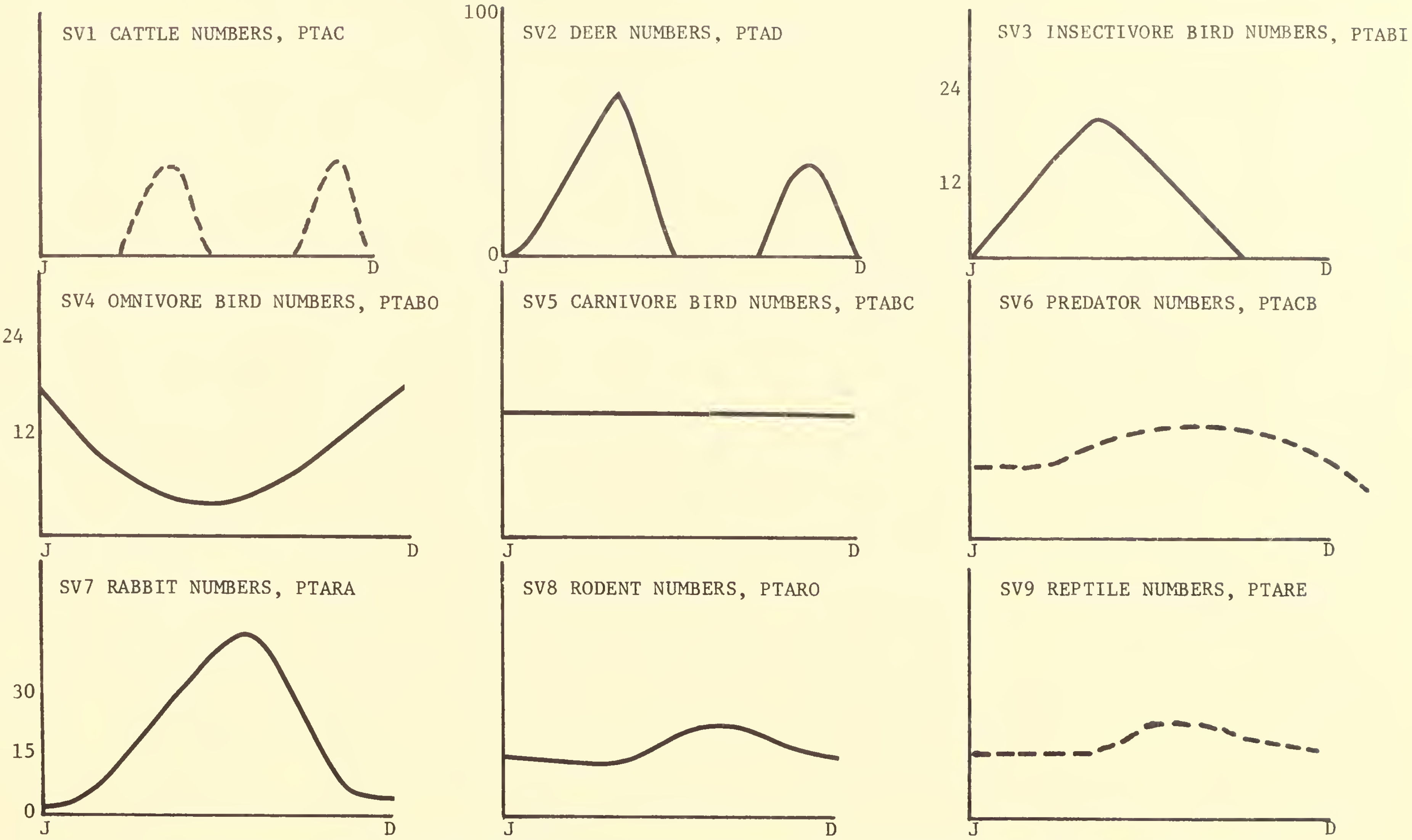

Figure 2-3 SIMPLIFIED DYNAMICS OF THE STATE VARIABLES OF THE TRACT C-b ECOSYSTEM CONCEPTUAL MODEL BASED ON 1974-1976 MEASUREMENTS AND ESTIMATES.

Similar to cattle, deer migrate into the system during the fall and move out to higher elevations in the spring. During much of the winter they are in the pinyon-juniper and chained rangelands. Deer use protected draws during severe weather. Agricultural meadows are used primarily during fall and early spring (Figure 2-3-PTAD). The deer are in the system longer than the cattle and occur in higher numbers. The deer begin arriving in the Tract area about the middle until the end of October and depart in the spring generally between about the 5th and the 10th of May. The numbers in the system are somewhat higher in the fall than in spring.

Insectivorous birds have peak numbers in the system in the late spring and early summer and low numbers in the fall and winter (Figure 2-3-PTABI). Omnivorous birds presumably are most abundant in the system during the fall and winter, with lower numbers present in the late spring and early summer (Figure 2-3-PTABO). Carnivorous birds, represented by the raptors, have relatively uniform numbers in the system year round (Figure 2-3-PTABC).

Mammalian predators are always present in the system, but their numbers increase each summer due to recruitment of young. Peak numbers probably are attained in late June or early July as attrition takes its toll, numbers decline to a minimum by late winter or early spring (Figure 2-3-PTACB).

Cottontail rabbits are fairly common in the system. They begin reproducing in the spring and reach peak numbers in middle to late summer before predation and natural mortality from other causes initiates a decline (Figure 2-3-PTARA). Low numbers are probably reached in late winter and early spring, when they begin increasing again. Small rodents fluctuate seasonally also (Figure 2-3-PTARO). Because some small mammals hibernate, numbers remain relatively constant until late winter or early spring, when they emerge.

The dynamics of reptile numbers is not well understood. It is hypothesized that their numbers increase during the relatively warm part of the year beginning in late May and peak probably in July or August (Figure 2-3-PTARE). They then decline in numbers until they estivate or hibernate in the fall. Thereafter, their numbers remain relatively uniform during the winter until activity begins again in the following spring.

A variety of arthropods occur within the system. Although preliminary sampling has taken place, there is a wide fluctuation in the numbers measured depending upon the particular taxonomic groups concerned. Overall, arthropod numbers peak in middle summer and are at their lowest level in early spring (Figure 2-4-PTAAR). Numbers of arthropods rapidly increase in the spring of

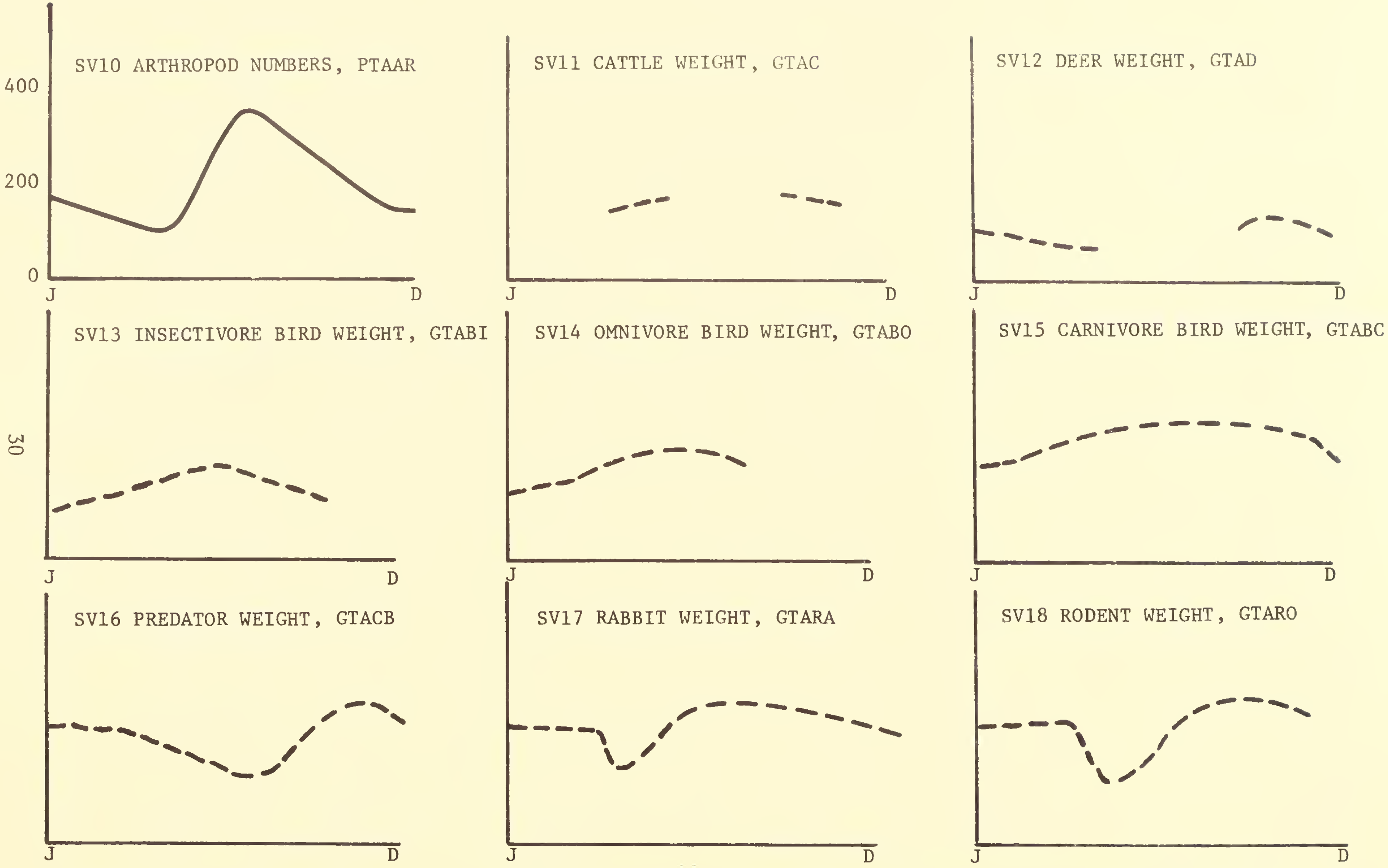

Figure 2-4 SIMPLIFIED DYNAMICS OF THE STATE VARIABLES OF THE TRACT C-b SYSTEM CONCEPTUAL MODEL BASED ON 1974-1976 MEASUREMENTS AND ESTIMATES

the year as hatching and metamorphosis takes place with increasing temperature and relatively favorable moisture and food conditions. There is at least a three-fold increase in numbers between early spring and middle summer, based on the number of arthropod larvae and some adults counted in the early spring population.

2.5.8 Animal Weights

Although not measured in the baseline studies, cattle weights can be expected to increase during the interval cattle are in the system in the spring; they would decrease slightly when they are in the system in the autumn. The autumn weights for adults would be greater than the spring weights (Figure 2-4-GTAC).

From the beginning of the year until the deer leave the system, weights would perhaps decrease slightly. Fawning occurs largely after the deer are out of the Tract C-b area. When the deer return to the system in the fall, adult weights are greater than when they left in the spring (Figure 2-4-GTAD).

Relatively little is known about the change in the weight of birds during their stay in the system. The relationships shown in Figure 2-4-GTABI, GTABO, and GTABC are only first-approximation estimates. In general, insectivorous birds would be the lightest and carnivorous birds the heaviest. During the period they are projected to be in the C-b system, insectivorous birds might reach their peak weights in June, omnivorous birds at about the same time, and carnivorous birds would carry their peak weight from late May until early October.

Little is known about mammalian predator weights in the Tract region. It is hypothesized that the lowest weight per individual in the population would be reached about June, at which time there are the greatest number of young-of-the-year (Figure 2-4-GTACB). The young grow rapidly during summer, and peak weight is reached in middle fall before food shortage causes a decline that continues until the following spring.

Rabbits and rodents can be expected to have similar weight dynamics. Low weights per individual in the population occur in the spring. The adults have a low weight at this time due to the stress of winter conditions, but the sharp drop in the spring shown in Figures 2-4-GTARA and 2-4-GRARO represents parturition. As the young grow rapidly, the average individual weight in the population increases to a peak in about July. These peaks are maintained during much of the summer but weights per individual begin to drop off in the fall.

The seasonal dynamics of the weight of reptiles on the Tract is speculative. The plot shown in Figure 2-5-GTARE is a first

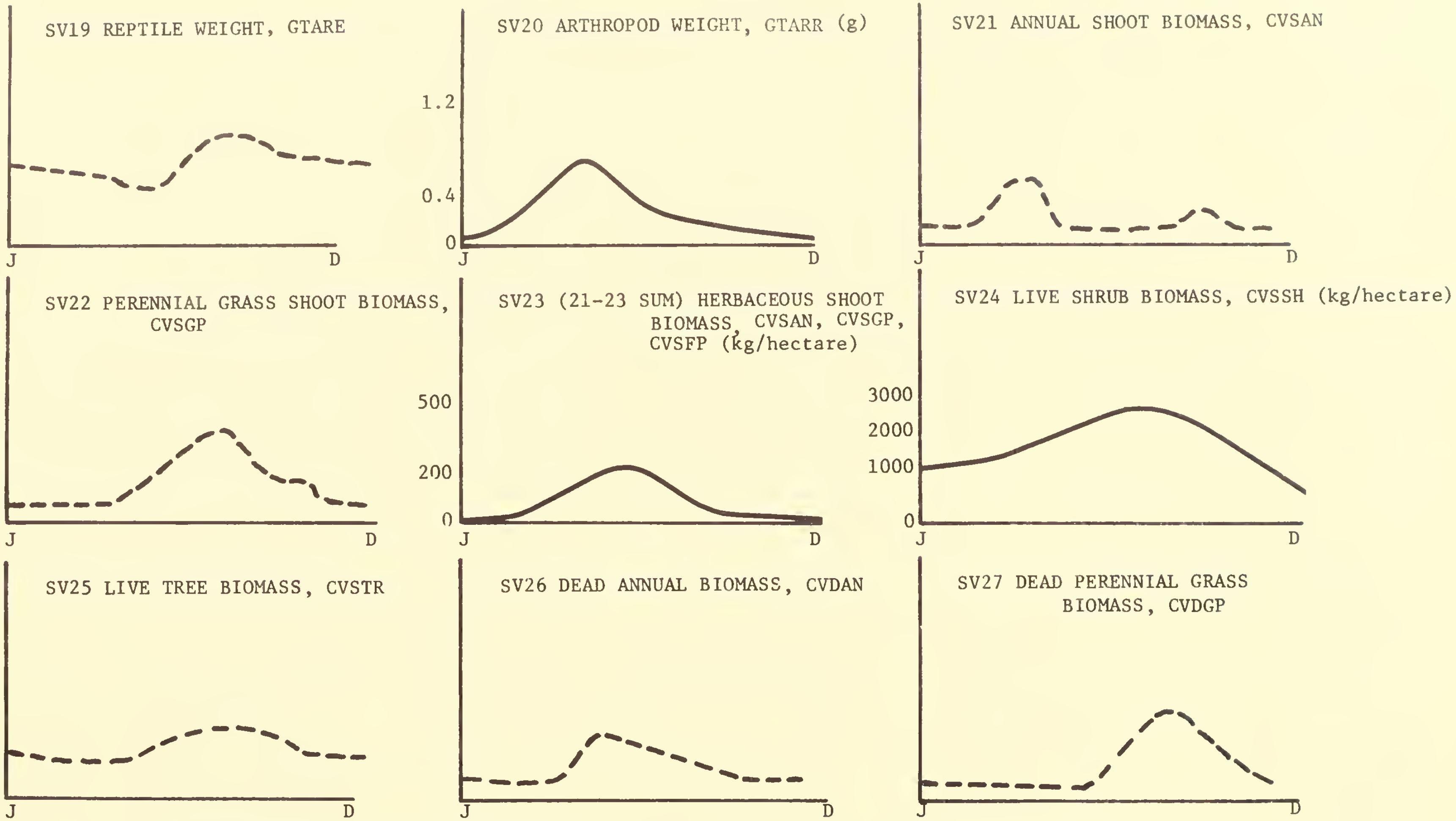

Figure 2-5 SIMPLIFIED DYNAMICS OF THE STATE VARIABLES OF THE TRACT C-b SYSTEM CONCEPTUAL MODEL BASED ON 1974-1976 MEASUREMENTS AND ESTIMATES

approximation. It is hypothesized that once reptiles emerge from hibernation in the spring and reproduce, the average weight per individual drops to its lowest values in April or early May. With growth of young and fattening of adults, peak weights would be reached during the hottest portion of the year, in July or August, before a decline begins. The loss of weight would be relatively rapid as temperatures cool and the animals begin hiberation.

Based on data collected from the Tract C-b area, peak arthropod weights are reached in the spring with lower values in the fall and winter and a decline through the summer (Figure 2-5-GTAAR).

2.5.9 Plant Biomass

Biomass of the live aboveground portions of five plant categories conceptualized for the C-b system model are shown in Figures 2-5-CVSAN, CVSGP, CVSFP, CVSSH, AND CVSTR. These biomass values are only for live shoots; standing dead biomass is discussed later.

Live shoots of annual plants are prominent only in the spring with a small amount of growth of winter annuals in the fall. Peak biomass values are probably found in April or May, but the plants die and shatter rapidly in the summer.

Although many of the perennial herbaceous plants are cool-season species, many of the perennial grasses and forbs could be expected to have their peak biomass in July, similar to the pattern shown in Figure 2-5-CVSGP. Because of the possibility of fall rainfall and regrowth, the decline in biomass of perennial herbaceous plants, which has been in progress since mid-summer, may be temporarily arrested with new growth in the fall. Figure 2-5-CVSFP shows results of field measurements wherein the herbaceous shoot biomass is totaled for annuals, perennial grasses, and perennial forbs. When the total of these categories is plotted, peak biomass values are in May to June.

The main period of growth of the woody plants on the C-b Tract is evidently later in the year than for herbaceous plants. Field measurements of the shrubs show peak standing crops are in July or August (Figure 2-5-CVSSH). Peak standing crop of live material in the shrubs is almost twice as high in August as it is in middle to late winter. The field data for shrubs from the C-b baseline studies presumably include twig materials older than the current annual growth. This helps account for the high biomass figures shown. The dominant trees in the C-b system are conifers, which maintain considerable amounts of live foliage throughout the year. It is presumed in Figure 2-5-CVSTR, however, that there is a slightly higher foliage biomass in the summer than at other seasons.

The seasonal dynamics pattern of standing dead biomass for herbaceous plants, and also to some degree for shrubs, complements the seasonal dynamics for live shoot biomass. Thus, dead plant biomass peaks after the decline of the live biomass (Figure 2-5-CVDAN, CVDGP, and Figure 2-6-CVDFP). For example, annual shoot biomass peaks in April for live material and in May or June for dead material. Where live biomass of perennial grass peaks in July, the peak values for dead perennial grass biomass are in August or early September. The values shown in Figure 2-6 CVDFP are for the sum of annual plants, perennial grasses, and perennial forbs standing dead biomass. These values are relatively constant throughout the year, with the lowest values in May and highest values in August.

The pattern is somewhat different for the woody plants than for the herbaceous plants. Peak biomass values for the shrubs are assumed to occur in October (Figure 2-6-CVDSH). For trees there is a relatively uniform but slightly increasing biomass. Much of the bole of the tree is considered to be standing dead. It is presumed that the forest is growing slightly or is nearly static over time. Thus, values are changing relatively little from year to year (Figure 2-6-CVDTR).

No field data were collected in the baseline study on standing crops of root biomass. Therefore, the curves presented in Figure 2-6-CVRAN, CVRGP, CVRFP, CVRSH, and CVRTR are based on reasoning about the C-b Tract categories as they relate to information from other systems. Live annual root biomass can be expected to increase at times similar to those when shoots are increasing. Thus, there is a similarity in the curves shown for shoot and root biomass (compare Figures 2-5-CVSAN and 2-6-CVRAN). For perennial grasses and perennial forbs, however, a great deal of root reserve material is depleted in the early growth stages of the shoots. Thus, as initial shoot growth is made there is considerable depletion of root biomass. At a point midway in shoot growth, however, root biomass begins to increase and it peaks at a date after the peak of live shoot biomass. This can be seen by comparing Figure 2-5-CVSGP and Figure 2-6-CVRGP.

Less is known about the seasonal dynamics of the live root biomass for woody plants than for herbaceous plants. Thus the patterns shown in Figures 2-6-CVRSH and CVRTR are untested hypotheses.

Field measurements of aboveground litter biomass are summarized in Figure 2-6-CLA. There are relatively uniform values of litter through the year, with slightly higher values in the fall than in other seasons. Very little is known for any ecosystem about the seasonal dynamics of the belowground litter biomass. This biomass category represents dead roots and other organic material in the soil. Thus, Figure 2-7-CLB is largely an untested hypothesis for ecosystem types similar to those of Tract C-b. Low values of

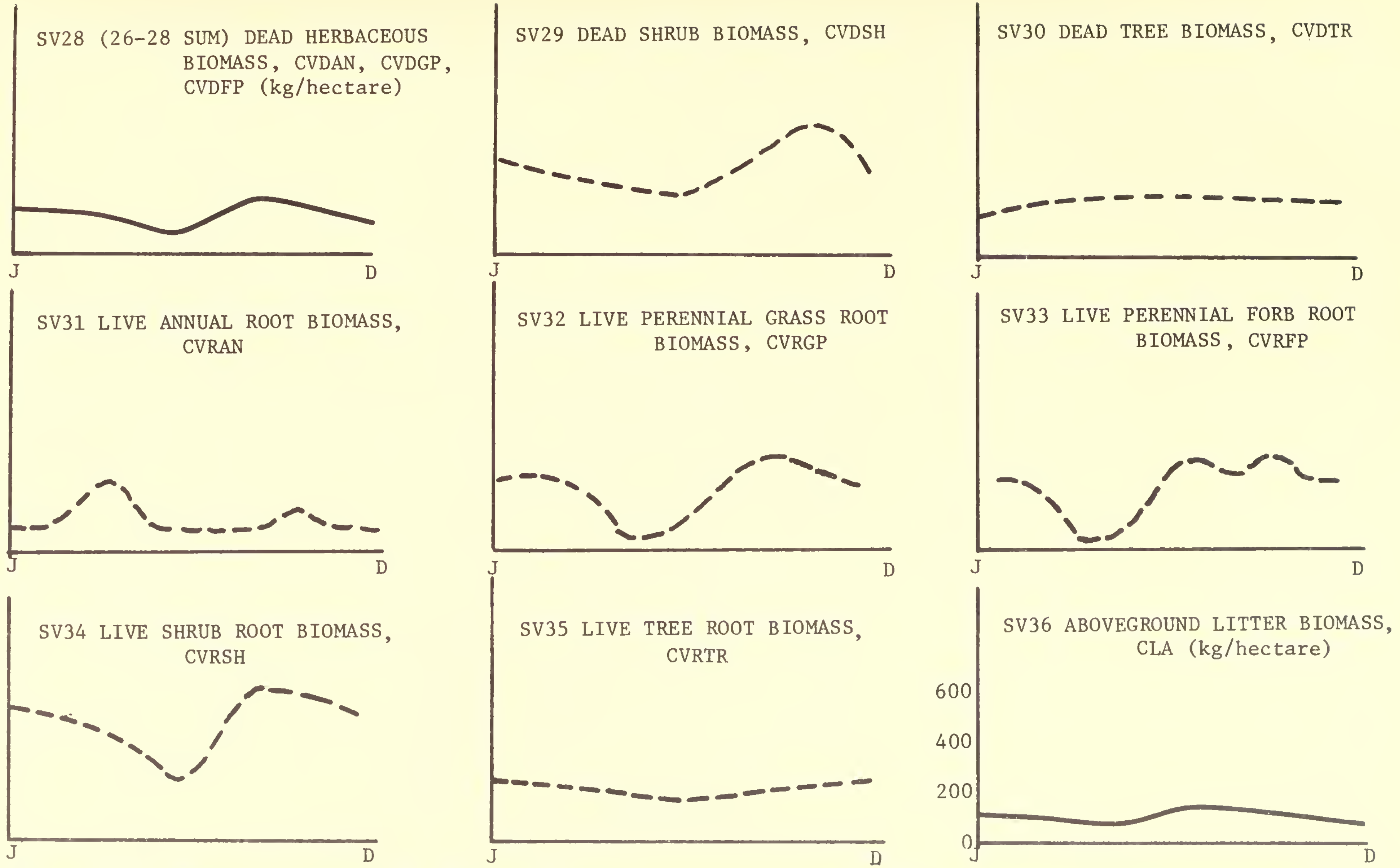

Figure 2-6 SIMPLIFIED DYNAMICS OF THE STATE VARIABLES OF THE TRACT C-b SYSTEM CONCEPTUAL MODEL BASED ON 1974-1976 MEASUREMENTS AND ESTIMATES

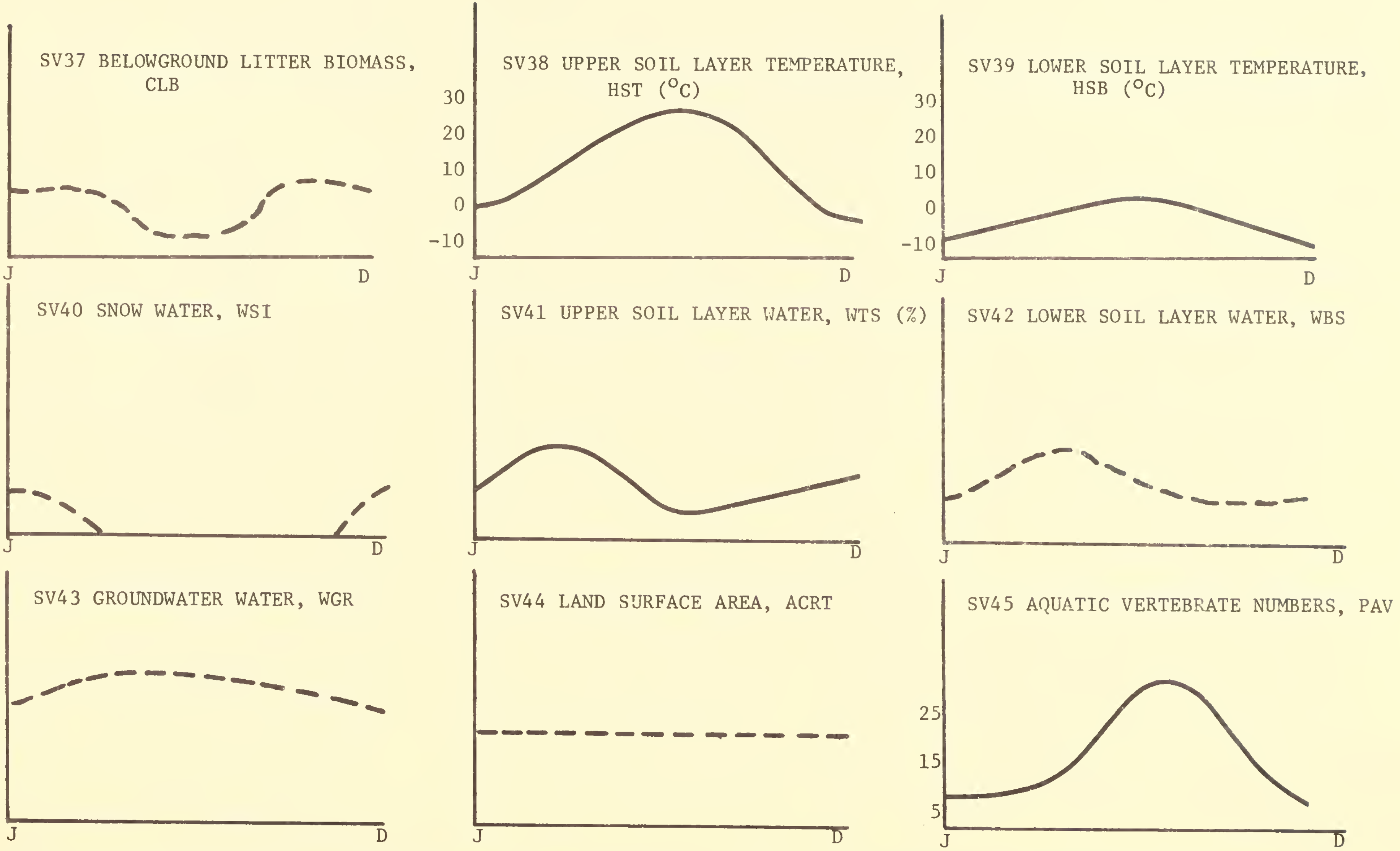

Figure 2-7 SIMPLIFIED DYNAMICS OF THE STATE VARIABLES OF THE TRACT C-b ECOSYSTEM CONCEPTUAL MODEL BASED ON 1974-1976 MEASUREMENTS AND ESTIMATES

belowground litter are reached in May or June, and high values in September or October. One can expect that the root-to-shoot ratio for vegetation of the Tract may be about 5:1. Soil water levels are high in early spring and decline to low levels in summer; soil temperatures increase during this interval. The belowground litter biomass curve dynamics were derived by considering the relationship of decomposition of organic material to these temperature and moisture trends.

2.5.10 Terrestrial Abiotic Variables

Soil temperature measurements for upper soil layers and lower soil layers as conceptualized herein are summarized from field measurements in Figures 2-7-HST and 2-7-HSB. The upper soil layer (0 to 25 cm.) shows much greater dynamics in temperature, as expected, than the lower soil layer (25 to 150 cm.). Peak soil values are reached in July or August for both the upper and lower soil layers.

The conceptual model developed in this volume identifies three levels of water within the terrestrial system--surface water including snow, upper soil layer water, and lower soil layer water. Depth ranges are the same as for heat. Snow may occur during much of the year on the Tract C-b system, but appreciable snow depths occur only in the late fall and winter interval as depicted in Figure 2-7-WSI. Measurements made of the soil water layer show peak values in May and minimal values in July (Figure 2-7-WTS). Soil water levels at lower layers in the soil could be expected to lag behind the peaks and troughs and have lower values than in the upper layer (Figure 2-7-WBS). The hypothesized pattern for groundwater, shown in Figure 2-7-WGR, is based upon the measurements made in wells on the Tract. This variable is an aggregate of four different classes of wells. (See Volume II, Section 2.2.3, of this report.)

The conceptual model developed here requires the calculation or tracing of the land's surface area. For baseline conditions, the land surface area remains constant, only to be changed within the year by the expansion and contraction of the aquatic surface area. (Figure 2-7-ACRT).

2.5.11 Aquatic Animals

Measurements were made of the numbers of aquatic vertebrates and invertebrates, and these data are summarized in Figures 2-7-PAV and 2-8-PAI. Peak numbers of invertebrates showed highest average values in July with very low values from middle October until middle April. High values for invertebrates were earlier in the year, i.e., in late spring and early summer, and the relative

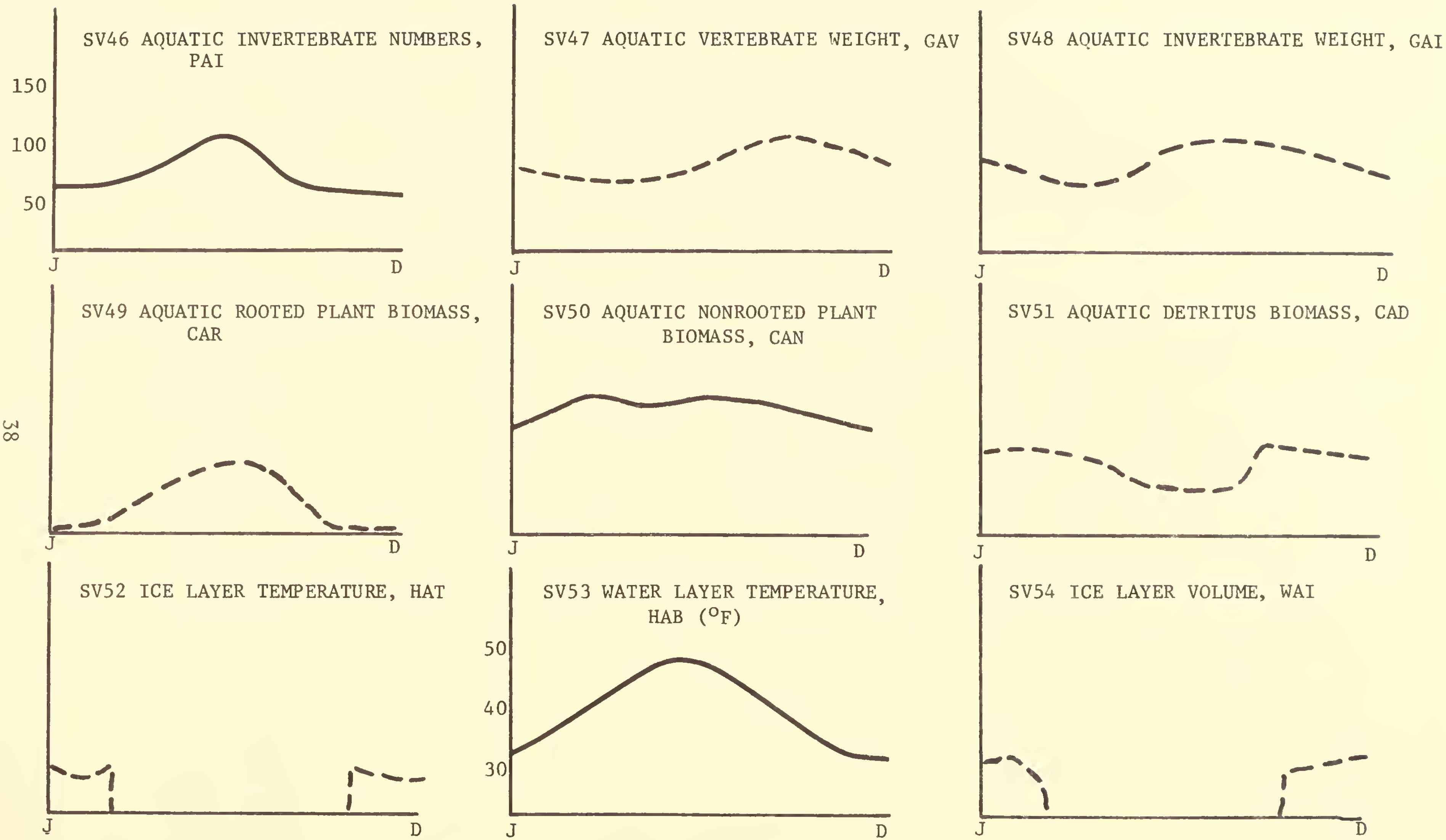

Figure 2-8 SIMPLIFIED DYNAMICS OF THE STATE VARIABLES OF THE TRACT C-b SYSTEM CONCEPTUAL MODEL BASED ON 1974-1976 MEASUREMENTS AND ESTIMATES

dynamics throughout the year were not as great for invertebrates as for vertebrates. Few data were available for the weights of the vertebrates or invertebrates, so Figures 2-8-GAV and 2-8-GAI represent hypothesized values.

2.5.12 Aquatic Plants

The plant material in Tract C-b's aquatic ecosystems is represented largely by the categories of rooted plants, nonrooted plants, and detritus. Field measurements were made only on the aquatic, nonrooted plant biomass, and this category of biomass in the system has relatively small change during the year. Probably, highest values occur in early spring to early summer, and lowest values occur in late fall and winter (Figure 2-8-CAN). Values for aquatic rooted plant biomass (both shoots and roots) are hypothesized in Figure 2-8-CAR and for the aquatic detritus compartment in Figure 2-8-CAD. It is expected that most of the rooted aquatic plants will make their peak growth during late spring and early summer at which time there is adequate water in the aquatic system and relatively warm temperatures. Later in the summer, although temperatures are sufficient for plant growth, many of the streams, springs, and seeps in the Tract area become dry, thus decreasing the live plant biomass. This is reflected also in the time-series curve for the aquatic detritus biomass. With the death of plant material in middle to late summer there would be an increase in detritus in late summer or autumn. These detritus levels remain fairly high, because decomposition rates are relatively low during fall and winter. When temperature begins to increase the following spring and while water levels are high, decomposition would be rapid, accounting for a decline in aquatic detritus biomass in late spring.

2.5.13 Aquatic Abiotic Variables

Abiotic state variables in the aquatic system include temperature of water compartments, volume of water compartments, and surface area of aquatic systems. The only variable of this set which was measured in field baseline studies was water temperature (Figure 2-8-HAB). High water temperatures are reached in early summer, according to an evaluation of the field data. This seems somewhat counter-intuitive, but it is based on a relatively large number of measurements. Water temperatures vary by about a factor of two from middle winter to early summer.

During winter a significant fraction of the water in the aquatic systems is in the form of ice, but no data are available on ice volume or temperature. Therefore, Figures 2-8-HAT and 2-8-WAI are hypothesized.

Flow rate data have been obtained at several aquatic sampling stations adjacent to or related to the Tract. However, water volume measurements and aquatic surface area measurements were not reported; thus the graphs in Figures 2-9-WAW and 2-9-ACRA are hypothesized.

2.6 Summary

This chapter lists and discusses the ecosystem components used in the model and their measured or postulated time-series behavior. Several state variables are identified at two levels of aggregation. The greater aggregation provides a convenient way of reducing the number of variables that must be considered, but at the expense of clarity and resolution. The disaggregated, or expanded, set of variables provides more detail where it is needed.

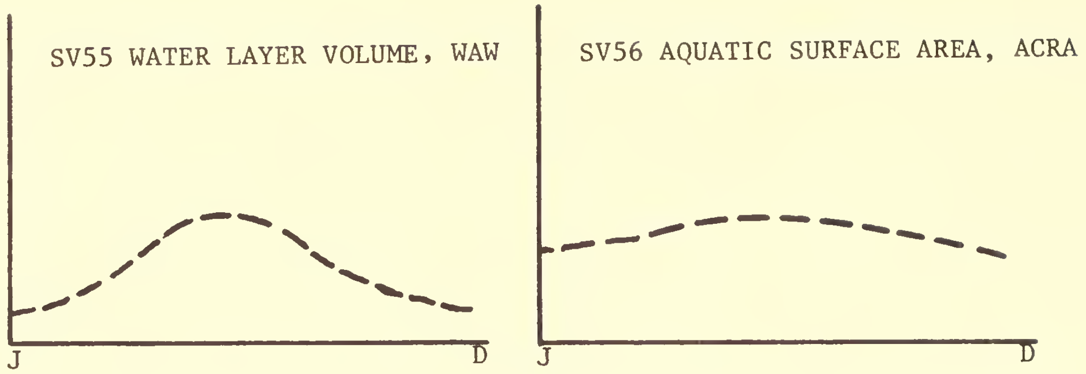

Figure 2-9 SIMPLIFIED DYNAMICS OF THE STATE VARIABLES OF THE TRACT C-b SYSTEM CONCEPTUAL MODEL BASED ON 1974-1976 MEASUREMENTS AND ESTIMATES

3 ECOSYSTEM PROCESSES

3.1 Introduction

The ecosystem components identified in Chapter 2 are linked by flows of matter or energy. Thus, the growth and demise of an annual plant can be viewed in terms of carbon accumulation in and dispersion from plant tissue, for example. Carbon flow can be directly related to biomass, which is measurable. The accumulation of biomass in plants can be related more or less directly to other variables, such as time, soil moisture, precipitation, solar radiation, etc. Similarly the transformation of plant biomass into animal biomass (through herbivores), decomposer biomass, and ultimately into soil organic matter can be traced conceptually and, with care, can actually be measured under certain field conditions.

The movement of carbon through the ecosystem, then, is one way of tracing interrelationships among the abiotic and biotic components of the system. In this example, carbon is a flow currency; i.e., it is a common element that flows between ecosystem components. Other possible flow currencies are elemental soil nutrients (phosphorus, nitrogen, and potassium), water, and heat. Conceptually currencies can also be animal or plant numbers and weights, units of area, and even units of value, such as dollars.

The flow rates of these currencies through the ecosystem control the rate of growth or decay of any particular ecosystem component. The flows themselves, however, are simply the reflection of various processes that actually control the rates of flow. For example, one of the processes that controls biomass flow from generation to generation is reproduction. For a finer resolution, the process of animal reproduction can be subdivided into at least three distinct subprocesses: breeding, gestation, and natality. Depending on the species, these processes might be affected by solar radiation, temperature, humidity, precipitation, density of population, food supply, etc.

This chapter identifies flow currencies that are used in the conceptual model of Tract C-b and the major processes that control the flows of these currencies.

3.2 Flow Currencies

Criteria for selecting currencies of flow were (1) broad commonality among many system components and (2) ease of measurement. Six currencies were used in our conceptual model: flow of population numbers for the various animals, weights of individual animals, biomass of plant and litter components, temperature of soil layers, water content of various terrestrial and aquatic subdivisions, and surface land area. Table 2-2 groups the aggregated state variables into flow currency subsystems.

3.3 Processes

The physical, chemical, and biological processes that transfer matter and energy from part to part of the environmental system account for the dynamics of the system state variables. The relationships of these flows and processes to the system state variables is illustrated in the simplified diagram of Figure 3-1. Five plant-dominated system compartments are identified: live shoots, live roots, standing dead, aboveground litter, and belowground litter. Three kinds of within-plant processes are identified: translocation, death, and shattering. Interseasonal dynamics for the five compartments are illustrated by time-series curves based on those presented in Chapter 2. Additional flows coupling carbon within the plant compartments to external non-plant portions of the system are also illustrated.

The processes that regulate flows within and among ecosystems are themselves controlled by certain characteristics of the ecosystems and by external driving variables. Numerous kinds of flows and processes can be identified when one expands to the total system the simple conceptualization shown in Figure 3-1 for only the plant portion of the system. Examples of the processes that regulate these flows were discussed in the ecological interrelationships section of the first annual report (C-b 1976b). The list of ecosystem processes appears in Table 3-1.

3.4 Relationships Between Tract C-b Flows and Processes

As stated earlier, the flows are the linkages among ecosystem components and subsystems, and the processes control the flows. Conceptually the flows must start and stop somewhere. The ultimate origins and destinations of currencies flowing through the system are called sources and sinks, respectively. Once the boundaries of the system are defined, the sources and sinks are placed outside the system to account conceptually for the appearance and disappearance of quantities of flow currencies.

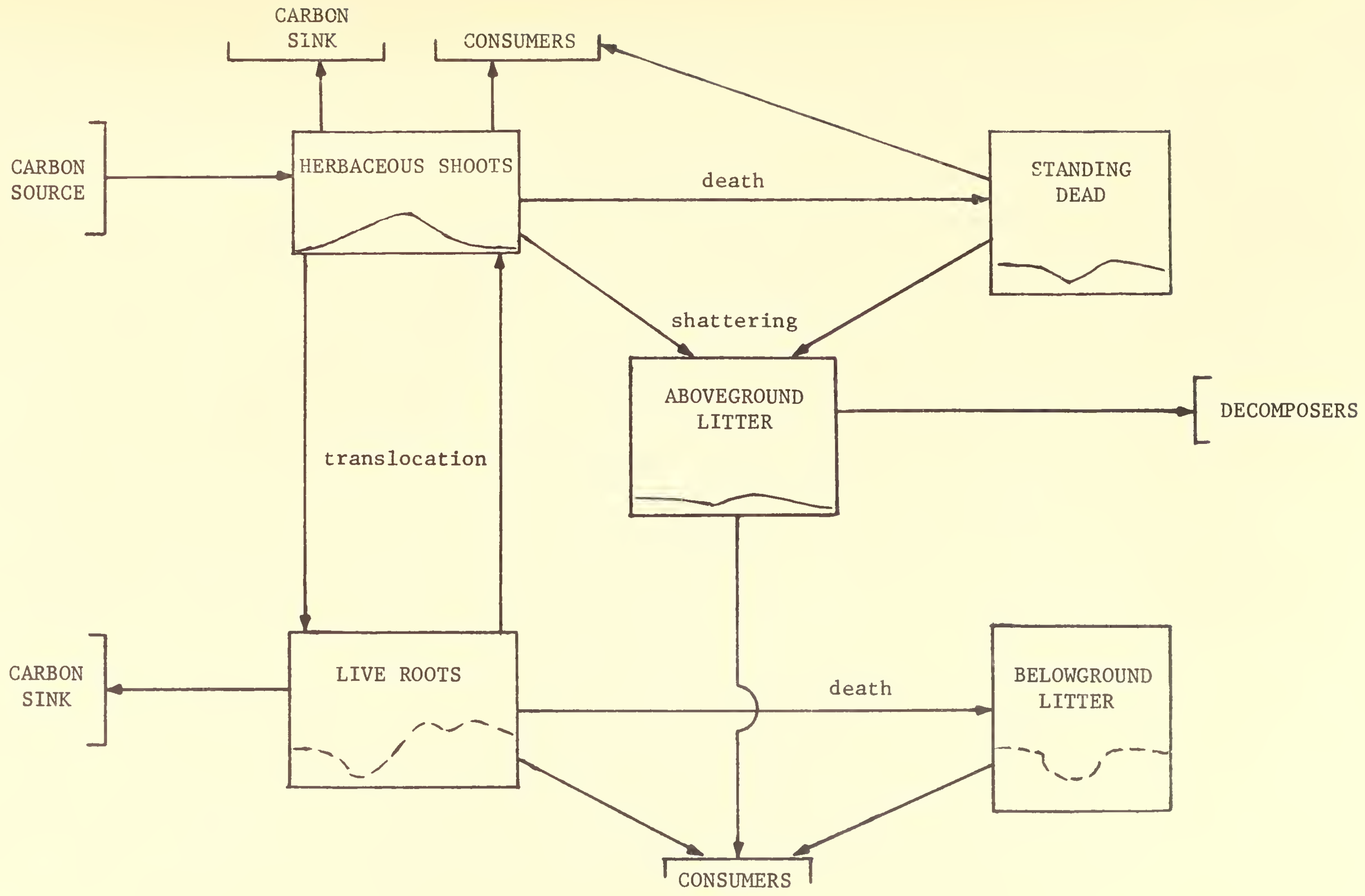

Figure 3-1 A SIMPLIFIED EXAMPLE OF CARBON FLOW THROUGH A PORTION OF THE ECOSYSTEM. ARROWS DENOTE FLOW, AND LABELS ARE SOME OF THE PROCESSES CONTROLLING THOSE FLOWS.

Table 3-1

LIST OF C-b ECOSYSTEM PROCESSES
AND THEIR ACRONYMS

Number	Process Name	Acronym
1	Animal Immigration	FTIMM
2	Animal Natality	FTNAT
3	Animal Emigration	FTEMI
4	Animal Mortality	FTMOR
5	Animal Growth	FTGRO
6	Animal Respiration	FTRES
7	Plant Photosynthesis	FTPHO
8	Animal Excretion Input	FTEXC
9	Animal Dead Body Input	FTDED
10	Plant Translocation Down	FTTRR
11	Plant Shoot Death	FTSHD
12	Plant Shoot Shattering	FTSHS
13	Plant Shoot Respiration	FTSHR
14	Plant Shoot Grazing Output	FTGRS
15	Plant Translocation Up	FTTRS
16	Plant Root Death	FTROD
17	Plant Root Respiration	FTROR

Table 3-1

(CONTINUED)

Number	Process Name	Acronym
18	Plant Root Grazing Output	FTGRR
19	Plant Dead Shattering	FTDES
20	Plant Dead Grazing Output	FTGRD
21	Aboveground Litter Decomposition	FTABO
22	Aboveground Litter Grazing Output	FTGRA
23	Belowground Litter Decomposition	FTBED
24	Belowground Litter Grazing Output	FTGRB
25	Heat Flow, Radiation In	FTRAD
26	Heat Flow, Convection In	FTCVI
27	Heat Flow, Conduction Down	FTCOD
28	Heat Flow, Reradiation Out	FTRER
29	Heat Flow, Convection Out	FTCVO
30	Heat Flow, Conduction Up (Soil)	FTCOU
31	Heat Flow, Conduction Down (Bedrock)	FTCDO

Table 3-1

(CONTINUED)

Number	Process Name	Acronym
32	Water Flow, Precipitation	FTPPT
33	Water Flow, Melting/Infiltration	FTSNI
34	Water Flow, Surface Evaporation	FTEVS
35	Water Flow, Soil Layer Infiltration	FTINF
36	Water Flow, Upper Soil Evaporation	FTEVU
37	Water Flow, Upper Soil Transpiration	FTTRU
38	Water Flow, Percolation to Groundwater	FTPER
39	Water Flow, Lower Soil Transpiration	FTTRL
40	Water Flow, Groundwater Springflow	FTSPF
41	Aquatic Vertebrate Natality	FANTV
42	Aquatic Invertebrate Natality	FANTI
43	Aquatic Vertebrate Mortality	FAMRV
44	Aquatic Invertebrate Mortality	FAMRI
45	Aquatic Vertebrate Growth	FAGRV

Table 3-1

(CONTINUED)

Number	Process Name	Acronym
46	Aquatic Invertebrate Growth	FAGRI
47	Aquatic Vertebrate Respiration	FARSV
48	Aquatic Invertebrate Respiration	FARSI
49	Aquatic Rooted Plant Photosynthesis	FAPHR
50	Aquatic Non-rooted Plant Photosynthesis	FAPHN
51	Aquatic Animal Excretion Input	FAEXC
52	Aquatic Dead Animal Body Input	FADED
53	Aquatic Rooted Plant Shoot Death	FASDR
54	Aquatic Rooted Plant Respiration	FARPR
55	Aquatic Rooted Plant Grazing Output	FAGRR
56	Aquatic Non-rooted Plant Shoot Death	FASON
57	Aquatic Non-rooted Plant Respiration	FARPN
58	Aquatic Non-rooted Plant Grazing Output	FAGRN
59	Aquatic Detritus Decomposition	FADEC
60	Aquatic Detritus Grazing	FAGRD

Table 3-1

(CONTINUED)

Number	Process Name	Acronym
61	Aquatic Radiation In	FARAD
62	Aquatic Convection In	FACVI
63	Aquatic Conduction Down	FACOD
64	Aquatic Reradiation Out	FARER
65	Aquatic Convection Out	FACVO
66	Aquatic Conduction Up	FACOU
67	Aquatic Conduction Down (Streambed)	FACDO
68	Aquatic Precipitation	FAPPT
69	Aquatic Melting (Ice)	FASNI
70	Aquatic Evaporation (Sublimation)	FAEVS
71	Aquatic Evaporation of Water	FAEVP
72	Aquatic Transpiration	FATRW
73	Aquatic Streamflow	FASTR
74	Animal Transfer In	FITRI
75	Animal Transfer Out	FITRO
76	Water Surface Runin	FIWRI

Table 3-1

(CONTINUED)

Number	Process Name	Acronym
77	Water Surface Runout	FIWRO
78	Litter Flow In	FILRI
79	Litter Flow Out	FILRO
80	Groundwater Flow In	FIGWI
81	Groundwater Flow Out	FIGWO
82	Land Flow Deforestation	FIDEF
83	Land Flow Rehabilitation	FIRHB
84	Land Flow Stand Establishment	FISTD
85	Land Flow Flooding	FIFLD

Within any ecosystem response unit, flows can be represented by a general coupling matrix. A coupling matrix identifies flows of matter or energy between components of an environmental system. The matrix for flows within the terrestrial ecosystem response unit is provided in Figure 3-2. Some 40 different kinds of flows are defined among the 13 different kinds of aggregated system state variables. Thus there are about three flows per variable in this subsystem conceptualization. The number of flows, however, is not equally divided among the different subsystems. The number is greater for the plant carbon subsystem and the water subsystem; it is less among the animal number and animal weight subsystems. Generally flows are unidirectional; almost all are above the diagonal of the coupling matrix. Exceptions are the linkages to and from plant roots and to and from the bottom heat layer in the soil.

A coupling matrix for the typical aquatic ecosystem response unit on Tract C-b is identified in Figure 3-3. Here there are 33 flows among the 11 system state variables giving a coupling ratio of 3.1, which is almost identical to that in the terrestrial subsystem. Again there are relatively more flows among the plant carbon subsystem state variables than for the other subsystems. But the aquatic submodel is relatively more balanced among subsystems than it is in the terrestrial situation. Only for the bottom layer heat state variable are flows bidirectional; there is only one flow listed below the diagonal in the coupling matrix.

3.5 A Food Web Matrix

One of the most fundamental processes in transfer of matter and energy among ecosystem components, and specifically between trophic levels, is the process of eating and the subprocesses connected with it (e.g., grazing, predation). We have developed a list of ecosystem components at a level of resolution that subdivides plants into functional categories and, further, into gross anatomical parts (Tables 2-2 and 2-6). Likewise animals are grouped into several functional categories. To trace the flow of carbon among all these components, it is helpful to construct a food web matrix (Fig. 3-4).

On Tract C-b there are potentially 17 categories of plant material and 10 types of animal material which can be eaten. There are 10 animal consumers plus decomposers to eat this organic material. An entry in a given row and column of the matrix indicates that a given "eaten" category is found as a major component of the diet of a specific "eater." Thus, for example, cattle consume primarily live and dead shoots of annuals, perennial grasses, perennial forbs, and shrubs. Because of their great diversity in feeding habits, the arthropods eat almost all of the categories of plant material.

TO FROM	population source	animal numbers	population sink	animal weight source	animal weights	animal weight sink	carbon source	live shoots	live roots	standing dead	above ground litter	below ground litter	carbon sink	heat source	top layer heat	bottom layer heat	heat sink	water source	surface water	top soil water	bottom soil water	groundwater layer	water sink
population source		1,2																					
animal numbers			3,4																				
population sink																							
animal weight source					5																		
animal weights						6																	
animal weight sink																							
carbon source								7			8,9												
live shoots									10	11	12		13,14										
live roots								15				16	17,18										
standing dead											19		20										
above ground litter													21,22										
below ground litter													23,24										
carbon sink																							
heat source															25,26								
top layer heat																27	28,29						
bottom layer heat															30		31						
heat sink																							
water source																			32				
surface water																				33			34
top soil water																					35		36,37
bottom soil water																						38	39
ground water layer																							40
water sink																							

Figure 3-2 A COUPLING MATRIX FOR FLOWS WITHIN TERRESTRIAL ECOSYSTEM RESPONSE UNITS FOR ANIMAL POPULATIONS AND WEIGHTS, CARBON BIOMASS, HEAT, AND WATER. NUMBERS REPRESENT PROCESSES LISTED IN TABLE 3-1.

TO FROM	population source	vertebrate animals	invertebrate animals	population sink	animal weight source	vertebrate weights	invertebrate weights	animal weight sink	carbon source	rooted plant biomass	nonrooted plant biomass	detritus	carbon sink	heat source	top layer heat	bottom layer heat	heat sink	water source	surface water	water	water sink
population source		41	42																		
vertebrate animals				43																	
invertebrate animals				44																	
population sink																					
animal weight source						45	46														
vertebrate weights								47													
invertebrate weights								48													
animal weight sink																					
carbon source										49	50	51,52									
rooted plant biomass												53	54,55								
nonrooted plant biomass												56	57,58								
detritus													59,60								
carbon sink																					
heat source															61,62						
top layer heat																63	64,65				
bottom layer heat															66		67				
water source																			68		
surface layer																				69	70
water																					71-3
water sink																					

Figure 3-3 A COUPLING MATRIX FOR FLOWS WITHIN AQUATIC ECOSYSTEM RESPONSE UNITS FOR ANIMAL POPULATIONS AND WEIGHTS, CARBON BIOMASS, HEAT, AND WATER. NUMBERS REPRESENT PROCESSES LISTED IN TABLE 3-1.

	EATERS										
EATEN	cattle	deer	bird insectivores	bird omnivores	bird carnivores	bobcats and coyotes	cottontail rabbits	rodents	reptiles	arthropods	decomposers
live shoots, annuals	X	X		X			X	X		X	
live shoots, perennial grasses	X	X		X			X	X		X	
live shoots, perennial forbs	X	X		X			X	X		X	
live shoots, shrubs	X	X		X			X	X		X	
live shoots, trees		X		X						X	
dead shoots, annuals	X	X		X			X	X		X	
dead shoots, perennial grasses	X	X		X			X	X		X	
dead shoots, perennial forbs	X	X		X			X	X		X	
dead shoots, shrubs	X	X		X			X	X		X	
dead shoots, trees		X		X							
live roots, annuals								X		X	
live roots, perennial grasses								X		X	
live roots, perennial forbs								X		X	
live roots, shrubs								X		X	
live roots, trees								X		X	
litter, above ground										X	X
litter, below ground										X	X
mobile animals, cattle						X					
mobile animals, deer						X					
mobile animals, bird insectivores					X	X					
mobile animals, bird omnivores					X	X					
mobile animals, bird carnivores											
mobile animals, coyotes											
fixed animals, rabbits					X	X			X		
fixed animals, rodents				X	X	X			X		
fixed animals, reptiles				X	X	X					
fixed animals, arthropods			X	X	X	X		X	X	X	

Figure 3-4 A SIMPLIFIED FOOD WEB MATRIX FOR THE CONCEPTUAL MODEL OF TRACT C-b.

This food web matrix then is a first step in conceptualizing the dietary selection calculations for a given organism. Initial estimates to be entered into the cells of the matrix would give the percentage a particular eaten category occurs in the diet of the eater on a year-long basis. For example, estimates from the baseline studies suggest that rodents in the C-b Tract system eat about 52 percent plant material taken from the live shoots, dead shoots, and live root categories; 40 percent of their diet consists of arthropods; and the remainder is taken from seeds (which are not represented in the model). Viewed from the perspective of the plants, the flows of plant material into the different consumers, or accumulation into woody material was estimated (Table 3-2) based on Tract observations and published data from similar systems (Whittaker and Woodwell 1969).

These estimates suggest that about half of the plant material produced in a given year goes through the saprophagic food chain rather than the biophagic food chain. In other ecosystems, e.g., shortgrass prairie, an even greater percentage would go through the saprophagic route. However, although few other data are available to support or refute the percentages listed above, the listed percentages are valuable at least for comparisons between the ecosystem response units.

3.6 Summary

In this chapter, the major flows in the Tract C-b environmental system and the processes that control them have been defined. This chapter also addresses, in a food-web matrix, an important subset of processes connected with flows between trophic levels. Detailed interrelationships between components and processes are discussed in Chapter 6.

Table 3-2

ANNUAL FLOWS OF PLANT MATERIALS INTO ANIMALS OR INTO ACCUMULATED WOODY TISSUE IN THREE ECOSYSTEM RESPONSE UNITS (PERCENT)

	UPLAND FOREST	GENERAL UPLAND	GENERAL BOTTOMLAND
	--------------	% consumed-	----------------
Rodents and Rabbits	4	4	4
Arthropods	3	3	2
Cattle	10	15	10
Deer	15	20	10
Birds	1	1	1
Decomposers	48	43	54
Accumulated woody tissue	20	15	20

4 INFLUENCES OF OIL SHALE DEVELOPMENT

4.1 Introduction

Chapters 2 and 3 identified important ecosystem components and processes on the extant Tract C-b environmental system. This chapter focuses on man-induced driving variables related to oil shale development and provides the basis for how oil shale development will influence the existing environment. The development driving variables are derived below from the Detailed Development Plan (C-b 1976a) and the modification of the Detailed Development Plan (C-b 1977). Although a preliminary list of oil shale driving variables was generated in Chapter 2, the level of resolution necessary to identify potential oil shale influences was not detailed enough. This chapter uses a series of matrices to identify a comprehensive list of oil shale development factors that might influence Tract C-b. This list suggests a basis for impact assessment and subsequent derivation of a logical monitoring program.

It should be emphasized here that mitigation procedures are part of the Detailed Development Plan and its modifications. This chapter simply identifies potential areas of impact in order to identify long-term monitoring needs.

4.2 The Oil Shale Development Matrix

The detailed development plan modification contains a phased timetable for different development activities (Figure I-B, C-b 1977). The five phases are listed across the top of the oil shale development matrix (Figure 4-1). The major activities associated with these phases are listed down the left side. The intersections are used to identify which major activities will occur in each phase.

4.3 The Activity Matrix

The major activities identified in the Development Matrix are composed of subactivities, many of which are common to more than one major activity. To gain greater insight into possible oil shale development influences, these sets of major activities and associated subactivities are linked in the Activity Matrix (Figure 4-2). The intersections in the matrix identify the associations of specific subactivities with major development activities.

MAJOR ACTIVITIES	OIL SHALE DEVELOPMENT PHASES				
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	Aug 77-Nov 77	Aug 77-Aug 82	Aug 79-Apr 82	Feb 81-Aug 82	Aug 82-2040
	Site Preparation	Preproduction Mining	Ancillary Facilities	Commercial Facilities	Operation
Build/Extend Roads	x		x	x	
Build Impoundment(s)	x	x			
Sink Shafts		x	x	x	
Mine (Development/Retort Construction)		x	x	x	x
Construct Underground Facilities			x	x	
Construct Surface Facilities			x	x	
Process Raw Materials/ operate			x x		x
Build Power Transmission Line(s)			x		
Build Staging Area (off-tract)			x		
Build Pipelines (off-tract)			x		
Build Commercial Facilities				x	

Figure 4-1 DEVELOPMENT MATRIX - OIL SHALE DEVELOPMENT PHASES AND THEIR ASSOCIATED MAJOR ACTIVITIES.

	MAJOR ACTIVITIES										
SUB-ACTIVITIES THAT PRODUCE ENVIRONMENTAL PERTURBATIONS	Build/Extend Roads	Build Impoundments	Sink Shafts	Mine	Construct Underground Facilities	Construct Surface Facilities	Process Raw Materials/Operate	Build Power Transmission Lines	Build Staging Area (off-tract)	Build Pipeline(s) (off-tract)	Build Commercial Facilities
Remove Vegetation	x	x	x			x		x	x	x	x
Store Equipment/Vehicles	x	x	x		x	x			x	x	x
Operate Equipment	x	x	x	x	x	x	x	x	x	x	x
Drill & Blast	x	x	x	x	x	x	x	x	x	x	x
Grade (Excavate & Fill)	x	x			x	x		x	x	x	x
Dispose of Waste	x	x	x	x	x	x	x		x	x	x
Pave or Surface	x	x				x			x		x
Fence	x	x	x			x			x		x
Increase Traffic	x					x			x		x
Disturb Vegetation	x	x	x			x		x	x	x	x
Build/Extend Roads		*	*			*		*	*	*	*
Remove Underground Water (dewater)			x	x	x		x				x
Dispose of Water			x	x	x		x				x
Sink Shafts				*							
Build Conveyor				x							
Operate Conveyor				x			x				
Crush Mined Shale				x			x				
Erect Structures					x	x		x	x		x
Exhaust Retorting Gasses							x				

* Road building or sinking shafts can be considered either major activities or subactivities.

Figure 4-2 ACTIVITY MATRIX - SUBACTIVITIES ASSOCIATED WITH MAJOR OIL SHALE DEVELOPMENT ACTIVITIES

4.4 The Perturbation Matrix

Each of the subactivities identified above may produce one or more perturbations to the environment. An environmental perturbation is a driving variable consisting of a disturbance that occurs in an environmental system. Many of the activities and subactivities result in some kind of structure (buildings, bridges, etc.) which itself produces perturbations simply by being there. These linkages are shown in the Perturbation Matrix (Figure 4-3).

The perturbations are all listed as verbs (create dust, emit particulates, etc.) to emphasize the fact that they actively impinge upon the environment.

4.5 The Role of Oil Shale Development Influences

These three matrices together provide information about the exact source of environmental perturbations as well as the anticipated timing within the oil shale development time frame. From a systems perspective, these perturbations are considered driving variables. The relationship of these variables to the overall functioning of the Tract C-b environmental system and the ecological subsystems that constitute it are discussed in the next chapter.

A brief summary of how these perturbations impinge upon the environment during different phases of the oil shale development is presented in Table 4-1. Various types of perturbations associated with a specific phase of operation are classified according to the type of impact they produce. The potential impacts are ordered according to interrelationships among air, water, soils, vegetation, wildlife, and noise.

Finally, for a first approximation of these influences from a systems perspective, a set of time-series graphs of aggregated oil shale development perturbations was estimated (Figure 4-4). These simplified groupings can be expanded into more detail, but this level of resolution is sufficient for conceptualization of these oil shale influences. The abcissa in each graph represents the increase of activities during the setup and operation of oil shale production over the entire time horizon projected for developing the shale; the ordinate represents the level of the driving variable throughout that horizon. This set of time-series graphs can be related to the oil shale driving variables of Figures 2-1 and 2-2, which represent seasonal fluctuations in these perturbations.

4.6 Summary

Using the Oil Shale Detailed Development Plan and its updated modification, Chapter 4 summarizes the major activities and the

	ACTIVE ENVIRONMENTAL PERTURBATIONS	SUBACTIVITIES																	STRUCTURES									
		DISTURB VEGETATION	REMOVE VEGETATION	OPERATE EQUIPMENT	DRILL AND BLAST	EXCAVATE AND FILL (GRADE)	DISPOSE OF SOLID WASTE	PAVE OR SURFACE	FENCE	INCREASE TRAFFIC	REMOVE UNDERGROUND WATER	DISPOSE OF PROCESS AND MINE DEWATERING WATER	SINK SHAFTS	BUILD CONVEYOR	OPERATE CONVEYOR	CRUSH MINED SHALE	ERECT STRUCTURES (BUILDINGS)	EXHAUST RETORTING GASES	SHAFTS	ROADS AND PAVED SURFACES	UNPAVED ROADS	FENCES, CULVERTS, & OTHER BARRIERS	IMPOUNDMENTS	TRANSMISSION LINES	PIPELINES	BUILDINGS	UNDERGROUND MINES	LAND FILLS
	CREATE FUGITIVE DUST	●	●	●	●	●	●	●	●	●			●	●	●	●					●							●
	CREATE ODORS			●						●		●						●										●
	CREATE NOISE AND VIBRATION			●	●		●			●				●	●	●	●											
METEOROLOGICAL	EMIT STEAM																	●										
	CREATE WATER VAPOR																											
	CREATE ICING																	●										
	CREATE FOG																	●										
	EMIT PARTICULATES AND AEROSOLS				●					●						●		●										
	EMIT SO_2																	●										
	EMIT H_2S																	●										
	EMIT NO																	●										
	EMIT NO_2																	●										
	EMIT NO_x			●						●								●										
	EMIT CO			●						●								●										
	EMIT CH_4																	●										
	EMIT NMHC (non-methane hydrocarbons)																	●										
	EMIT THC (total hydrocarbons)			●						●								●										
	EMIT OZONE AND OTHER OXIDANTS																	●										
	EMIT ARSENIC																	●										
	EMIT MERCURY																	●										
	EMIT SELENIUM																	●										
HYDROLOGICAL	ALTER SURFACE RUNOFF	●	●			●		●				●					●			●	●	●				●		●
	ALTER PEAK FLOWS (flash flooding)	●	●			●		●									●			●	●					●		●
	ALTER SEDIMENTATION	●	●			●						●									●							●
	ALTER EVAPORATION											●								●			●			●		
	ALTER SEEPAGE					●						●											●					
	ALTER WATER TABLE LEVELS					●					●	●	●							●			●				●	
	ALTER DOWNSTREAM FLOW	●	●			●		●			●	●					●			●	●					●		●
	ALTER STREAM CHANNELS					●					●																	
	ALTER SURFACE CHEMICAL COMPOSITION						●				●	●						●										●
	ALTER GROUNDWATER CHEMICAL COMPOSITION						●				●	●																●
	ALTER GROUNDWATER FLOW SYSTEMS				●	●					●		●						●								●	
TOPOGRAPHIC	CREATE LANDSLIDES	●	●		●	●		●					●							●	●						●	●
	ALTER CONTOUR OF LAND					●		●												●	●							●
	ALTER SURFACE DRAINAGE PATTERNS					●							●						●								●	●
	CREATE COMPACTION			●		●		●		●				●			●											
EDAPHIC	CREATE EROSION	●	●	●		●	●					●		●			●				●							●
	REMOVE ALL VEGETATION		■			●																						
	ALTER HUMUS CONTENT	●	●	●		●	●																					
	MIX SOIL PROFILE				●	●	●																					
GEOLOGIC	CAUSE GROUND TO SUBSIDE				●	●							●						●								●	
	EXPOSE SHRINK/SWELL CLAYS				●	●													●								●	
BIOLOGICAL	DISTURB VEGETATION	■		●																								
	INCREASE ROAD KILLS																			●	●							

● These perturbations are identified as being associated with the corresponding activities and structures.

■ These can be considered either subactivities or perturbations

Figure 4.3 PERTURBATION MATRIX — ENVIRONMENTAL PERTURBATIONS GENERATED BY ASSOCIATED OIL SHALE DEVELOPMENT SUBACTIVITIES

Table 4-1 POTENTIAL IMPACTS OF OIL SHALE DEVELOPMENT ACCORDING TO PHASE OF OPERATION

	Potential Impacts	Perturbations	Site Prep./ Pre-Construction	Pre-production Mining	Ancillary Facilities	Commercial Facilities Construction	Commercial Operation
I.	Air-Air	a. Air Pollution from Oil Shale Plant (Temporal/Spatial)					
		SO_2			x		x
		Particulates	x	x	x	x	x
		NO_2			x		x
		NMHC			x		x
		CO			x		x
		Oxidant			x		x
		Reduced Visibility			x		x
		Odors			x		x
		Water vapor/Stream releases/Icing/Fog			x		x
		b. Air Pollution in Traffic Corridors					
		NO_x	x	x	x	x	x
		CO	x	x	x	x	x
		THC	x	x	x	x	x
		Fugitive Dust	x	x	x	x	x
		c. Air Pollution from Mine					
		H_2S			x	x	x
		CO		x	x	x	x
		Mine Dust		x	x	x	x
		THC		x	x	x	x

Table 4-1 (CONTINUED)

Potential Impacts	Perturbations	Site Prep./ Pre-Construction	Pre-production Mining	Ancillary Facilities	Commercial Facilities Construction	Commercial Operation
II. Air-Water	a. Water Pollution from Fugitive Dust		x	x	x	x
	b. Trace Elements in Surface Waters from Air Emissions					
	Arsenic			x	x	x
	Mercury			x	x	x
	Selenium			x	x	x
	Others			x	x	x
III. Air-Soil	a. Fugitive Dust					
	Construction, Power & Pipe Lines		x	x	x	
	Haulage Roads		x	x	x	
	Shale Piles			x	x	x
	b. Trace Element Fallout from Air Emissions			x		x
IV. Air-Vegetation						
	a. Pollution Dose Effects on Vegetation					
	Ozone			x	x	x
	Synergistic Effects SO_2+O_3; SO_2+NO_2			x	x	x
	Influence of Removal Processes			x	x	x
	Trace elements			x	x	x
	b. Pollution Isopleths-Patterns in Space					
	SO_2			x		x
	Particulates			x		x
	Oxidant			x		x
	Locations of Bio-control Plots			x		x

Table 4-1 (CONTINUED)

Potential Impacts	Perturbations	Site Prep./ Pre-Construction	Pre-production Mining	Ancillary Facilities	Commercial Facilities Construction	Commercial Operation
V. Air-Wildlife						
	a. Purely Climatological Effects on Populations	x	x	x	x	x
	b. Possible Pollutant Isoplath Influence			x	x	x
VI. Noise-Noise						
	a. Noise Pollution					
	Construction Activity	x	x	x	x	x
	Traffic Corridors	x	x	x	x	x
	Oil Shale Plant			x	x	x
	Mine		x	x	x	x
VII. Noise-Wildlife						
	a. Population Relocation	x	x	x	x	x
	b. Stress	x	x	x	x	x

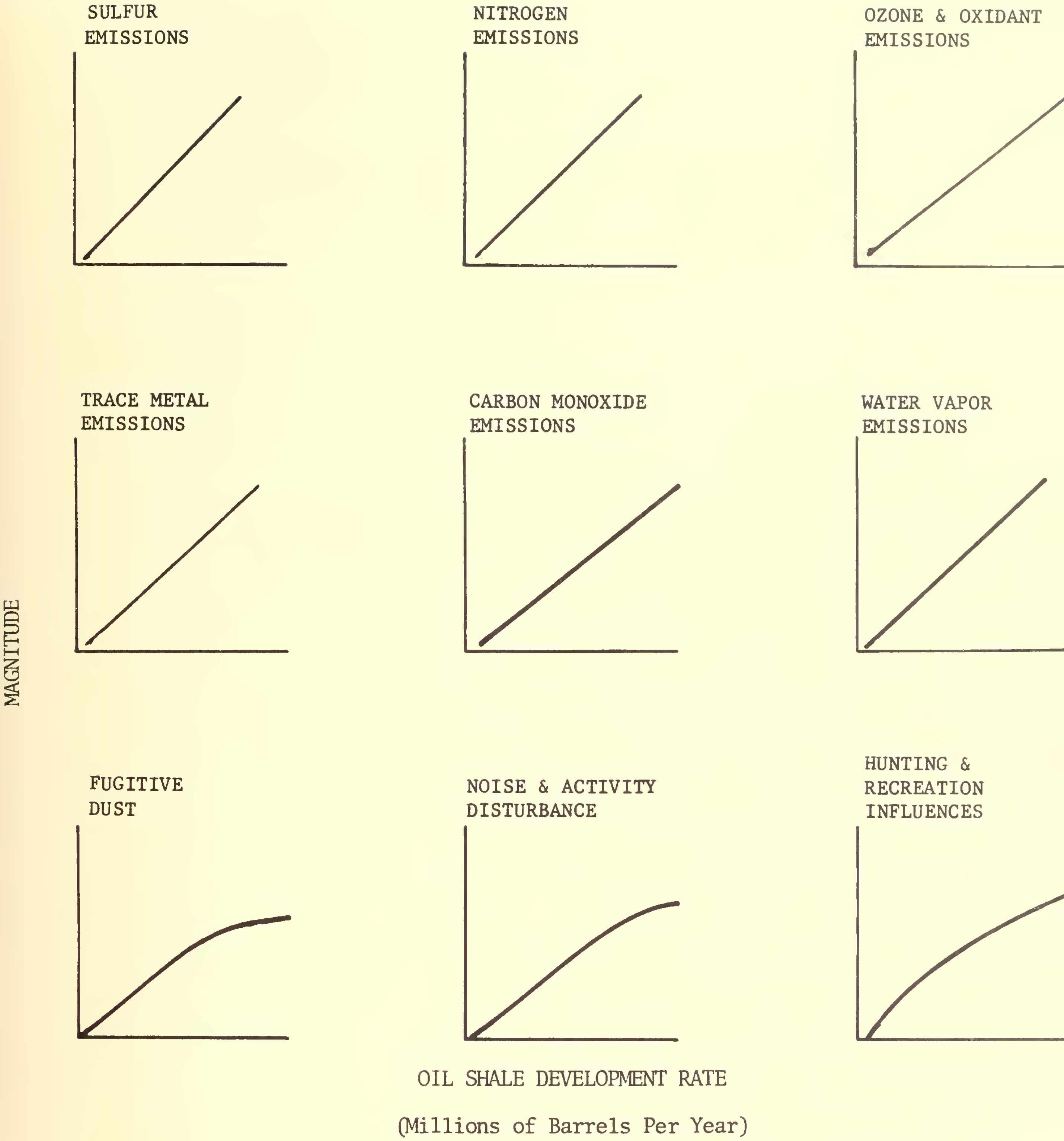

Figure 4-4 IMPACT OF OIL SHALE DEVELOPMENT ON DEVELOPMENT-CONTROLLED DRIVING VARIABLES FOR THE CONCEPTUAL MODEL

related subactivities associated with development of oil shale. It uses this list of activities to identify environmental perturbations that might be the result of that development. Some preliminary potential impacts are presented, and the time dynamics of various oil shale development influences are estimated for the life of the project.

5 A HOLISTIC PERSPECTIVE ON THE TRACT C-b ENVIRONMENTAL SYSTEM

5.1 Introduction

Earlier chapters analyzed the structural and functional aspects of the Tract C-b environmental system separately. This chapter synthesizes the components and processes discussed earlier into a holistic view of the Tract C-b system by showing how structure and function are interlinked. Holism is the view that environmental systems are correctly seen in terms of interacting wholes, or subsystems. Such holism is essential to understanding the interrelationships and interdependencies among state variables, driving variables, and system processes on Tract C-b. The perspective developed in this chapter provides a sound, logical framework for planning mitigation and monitoring activities in the Tract C-b system.

Since the Tract environmental system is not homogeneous, Section 5.2 discusses the entire Tract as a "system of subsystems," each of which functions slightly differently from the others. An initial holistic conceptual model developed in Section 5.3 diagrams how these subsystems are linked and interrelated. Section 5.4 integrates the state and driving variables into a master "Effects Matrix," which shows what environmental processes are affected by which state and driving variables. How these system processes are controlled by the system components is discussed in Section 5.5. Finally, a set of flow-control diagrams integrates information from the preceding sections in Section 5.6.

The matrix and diagrams presented in this chapter set the stage for identifying and tracing the interrelationships that potentially need to be mitigated and/or monitored in the system.

5.2 A System of Subsystems

The Tract C-b environmental system is a multi-dimensional conglomerate of many interrelated hierarchies of subsystems. Ecosystem response units constitute one type of subsystem; the spatial heterogeneity discussed in Chapter 2 requires that the Tract C-b area be subdivided conceptually into these units.

Another way of classifying subsystems is by the flows of matter or energy; thus, five flow currency subsystems are identified in Chapter 3: carbon, animal numbers, animal weights, heat and water. Figure 5-1 presents a simplified conceptual view of some Tract C-b subsystems within the total system framework. This diagram, which serves as an example, is discussed in detail in Appendix C, along with more elaboration of how the subsystem networks were developed.

The variables in the five flow currency subsystems are linked by the material flows, as described in Chapter 3, Figures 3-2 and 3-3. These currency subsystems are linked within the Tract C-b environmental system by the subsystems called ecosystem response units. In other words, similar processes control the flows within all ecosystem response units, and the flow currencies permit exchange of matter or energy between ecosystem response units.

For example, Figure 5-2 illustrates flows of surface water and alluvial groundwater between ecosystem response units. Water can flow from the upland forest types and the general upland types into the bottomland and hence into the aquatic systems. This is logical for the surface water flows, but is only hypothetical for the alluvial groundwater flows; more information is needed on groundwater flow systems coupling ecosystem response units. It is assumed that the inter-area litter flows would follow surface water flows.

In addition to transfer of material among ecosystem response units, the surface area of these units themselves will change under oil shale development. Table 2-3 lists two general types of ecosystem response units anticipated to result from the development: upland and bottomland rehabilitated sites. These transformations of surface area may be regarded conceptually as flows of land surface from one ecosystem response unit into another. Rehabilitated sites may arise from different types of development activities, but the fundamental process of rehabilitation would be generally the same for all. Figure 5-3 presents a rehabilitation strategy that includes site preparation, planting, and subsequent management of the seeded stand. This management must be continued for many years' time because of the greatly changed nature of the soil substrate and microclimate. After oil shale development has taken place over a period of years there would be rehabilitated sites in different stages of development. However, the greatest changes in the reseeded stands would take place within the first three years. Some three "age classes" of rehabilitated stands are visualized for the C-b Tract system conceptual model. These age classes could exist on lands that were originally uplands or lands that were originally bottomlands. Rehabilitated sites are considered as ecosystem response units, and the flow currency between these units is land surface.

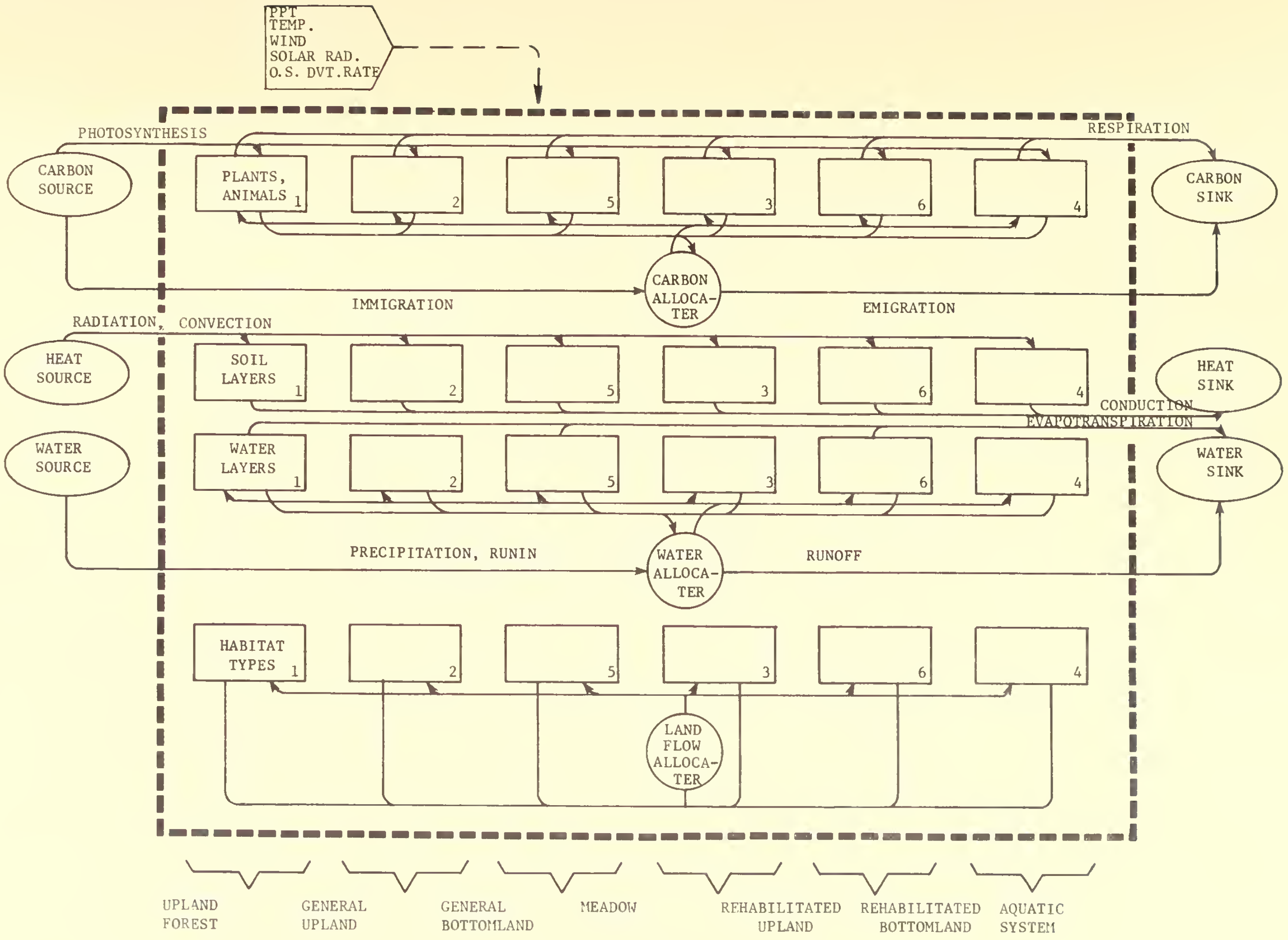

Figure 5-1 A SIMPLIFIED CONCEPTUAL VIEW OF THE GENERAL TRACT C-b SYSTEM WITH CARBON, HEAT, AND WATER FLOWS DEFINED. DASHED BOUNDARY ENCLOSES THE SYSTEM. DRIVING VARIABLES, SOURCES, AND SINKS ARE EXTERNAL TO THE SYSTEM.

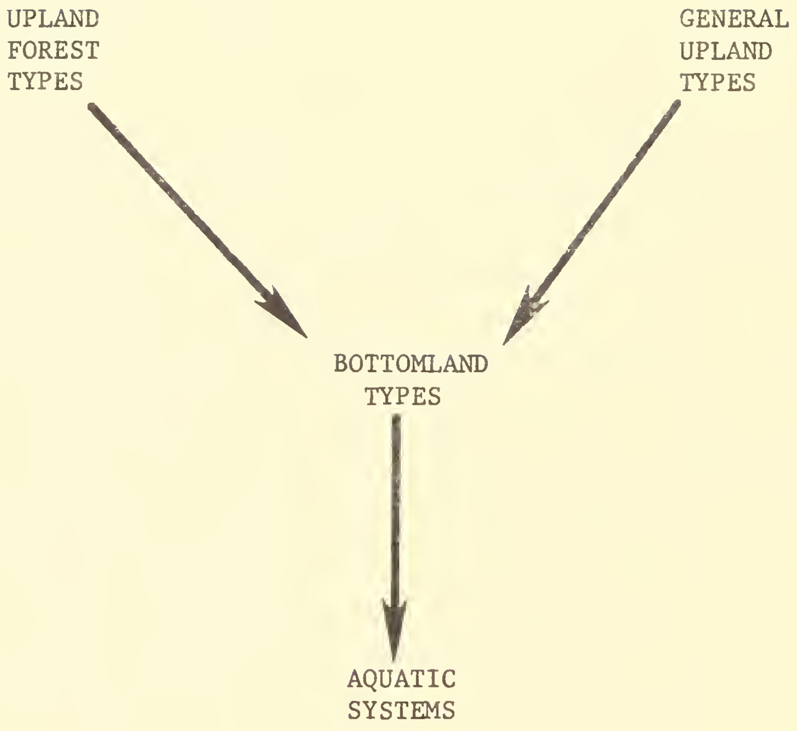

Figure 5-2 SIMPLIFIED SURFACE WATER AND ALLUVIAL FLOW ROUTES IN THE TRACT C-b SYSTEM

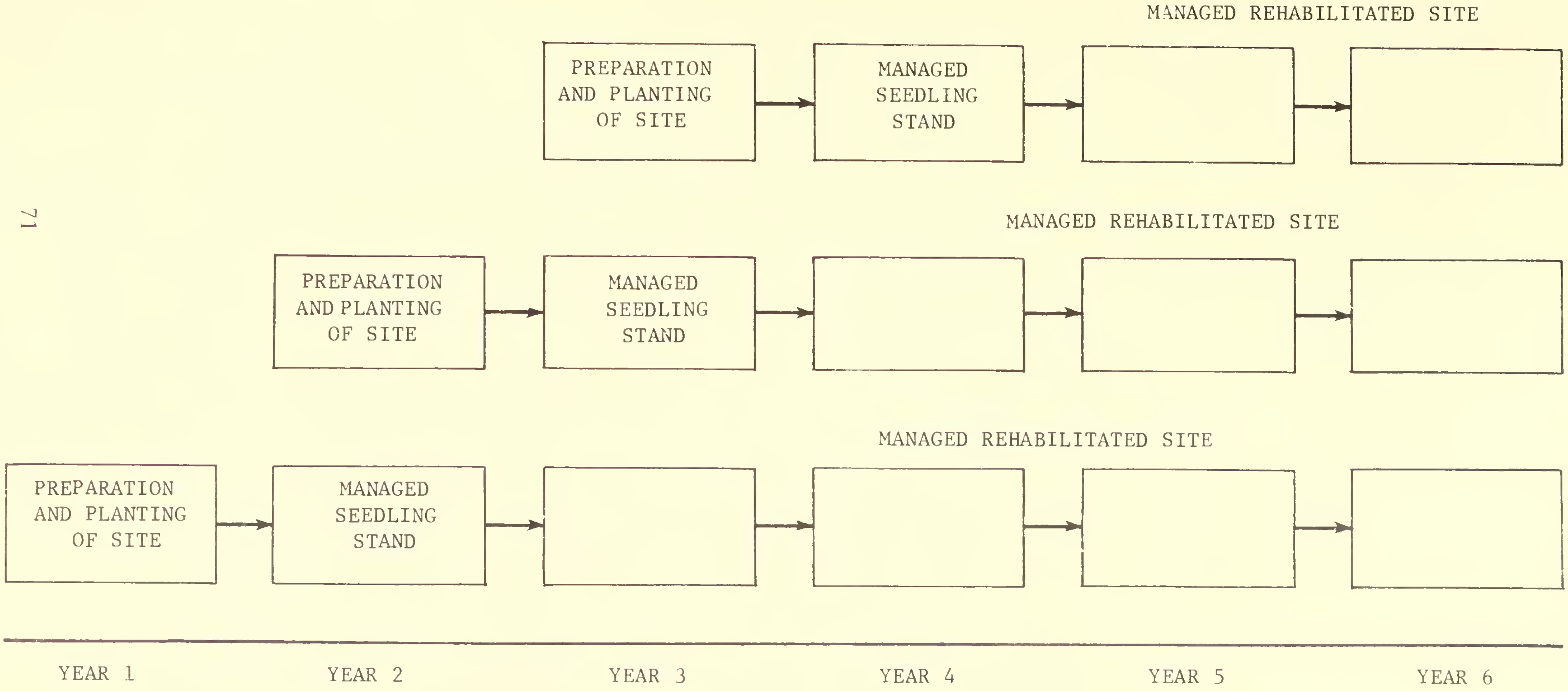
MANAGED REHABILITATED SITE
PREPARATION AND PLANTING OF SITE
MANAGED SEEDLING STAND
MANAGED REHABILITATED SITE
PREPARATION AND PLANTING OF SITE
MANAGED SEEDLING STAND
MANAGED REHABILITATED SITE
PREPARATION AND PLANTING OF SITE
MANAGED SEEDLING STAND
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6

Figure 5-3 LAND AREA CHANGES IN THE PROCESS OF REHABILITATION OF DISPOSAL, STORAGE SITES, AND LOCATIONS DISTURBED IN CONSTRUCTION ACTIVITY

Including three recovery stages on each of two types of rehabilitated types expands the total number of potential ecosystem response units to 11. Considering the movement of animals among the ten terrestrial ecosystem response units and considering movement of water and litter aboveground and water belowground among ecosystem response units, another series of flows are identified. These are illustrated in the inter-unit coupling matrix shown in Figure 5-4. Although the coupling matrix shows that there can be animal movements among all the ecosystem response units, in reality, the matrix would not be full as shown here. Some animals essentially will be restricted to specific ecosystem response units and will live and die there without migrating. Thus, the exact number of flows among units is uncertain. Only general classes of flows connecting these subsystems are identified.

5.3 A Holistic Conceptual Model

Using the coupling matrices of Figures 3-2, 3-3, and 5-4, and expanding the simplified conceptual diagrams of Figure 5-1 and Appendix C, it is possible to derive a detailed general subsystem structure for typical ecosystem response units (Figure 5-5). Driving variables impacting the system are at the top of the diagram outside the conceptual system, which is enclosed by the dashed-line boundary. Each driving variable and system state variable is identified by its general name and its subscripted acronym. The driving variables are shown in blocks or groups. For the terrestrial ecosystem response unit, up to 10 animal categories and five plant categories are identified as system state variables. The individual processes that control the flows between variables are numbered in triangles according to the same system used in the coupling matrices of Figures 3-2 and 3-3. These processes are listed in Table 5-1 and in the User's Reference (Appendix F). Sources and sinks for animal numbers, animal weights, plant carbon, heat, and water are identified. Circles in Figure 5-5 contain the conceptual controls for animal transfer, litter transfer, surface water flow, and groundwater flow.

Table 5-1 identifies 85 processes by name and acronym. It also includes the source and destination compartments. Processes 1 through 40 control terrestrial flows within an ecosystem response unit, and 41 through 73 are the aquatic processes. Processes 74 through 85 control the flows between ecosystem response units. Processes are variously subscripted so that there are conceptually more than 1000 possible processes, although the actual number is uncertain because of the lack of clear specifications about which animals may move among ecosystem response units. A full listing of variables and processes appears in Table 5-2 and in the User's Reference. It is now possible to develop a total-system flow diagram. This is shown in Figure 5-6.

Table 5-1

LIST OF PROCESSES, FLOW CURRENCY SUBSYSTEMS, ACRONYMS, FLOW SOURCES, AND FLOW DESTINATIONS FOR THE CONCEPTUAL MODEL OF THE TRACT C-b SYSTEM.

NO.	SUBSYSTEM	PROCESS	ACRONYM	*SUBSCRIPT LIMIT			FLOW SOURCE	FLOW DESTINATION
				I	J	K		
1	Animal Population (P)	immigration	FTIMM(I,J)	10	10		CSS	PTA(I,J)
2		natality (including predation)	FTNAT(I,J)	10	10		CSS	PTA(I,J)
3		emigration	FTEMI(I,J)	10	10		PTA(I,J)	PSS
4		mortality	FTMOR(I,J)	10	10		PTA(I,J)	PSS
5	Animal Weights (K)	growth	FTGRO(I,J)	10	10		GSS	GTA(I,J)
6		respiration	FTRES(I,J)	10	10		GTA(I,J)	GSS
7	Plant Carbon Biomass (C)	photosynthesis	FTPHO(I,J)	10	5		CSS	CVS(I,J)
8		excretion input	FTEXC(I,J)	10	10		CSS	CLA(I)
9		dead animal input	FTDEO(I,J)	10	10		CSS	CLA(I)
10		translocation to roots	FTTRR(I,J)	10	5		CVS(I,J)	CVR(I,J)
11		shoot death	FTSHD(I,J)	10	5		CVS(I,J)	CVD(I,J)
12		shoot shattering	FTSHS(I,J)	10	5		CVS(I,J)	CLA(I,J)
13		respiration, shoot	FTSHR(I,J)	10	5		CVS(I,J)	CSS
14		grazing output, shoot	FTGRS(I,J,K)	10	5	10	CVS(I,J)	CSS
15		translocation to shoots	FTTRS(I,J)	10	5		CVR(I,J)	CVS(I,J)
16		root death	FTROO(I,J)	10	5		CVR(I,J)	CLB(I)
17		respiration, root	FTROR(I,J)	10	5		CVR(I,J)	CSS
18		grazing output, root	FTGRR(I,J,K)	10	5	10	CVR(I,J)	CSS
19		shattering, dead	FTDES(I,J)	10	5		CVD(I,J)	CLA(I)
20		grazing output, dead	FTGRD(I,J,K)	10	5	10	CVD(I,J)	CSS
21		decomposition, aboveground	FTABD(I)	10			CLA(I)	CSS
22		grazing output, litter aboveground	FTGRA(I,I,K)	10	1	10	CLA(I)	CSS
23		decomposition, belowground	FTBED(I)	10			CLB(I)	CSS
24		grazing output, litter belowground	FTGRR(I,I,K)	10	1	10	CLB(I)	CSS
25	Heat (H)	radiation	FTRAD(I)	10			HSS	HST(I)
26		convection in	FTCVI(I)	10			HSS	HST(I)
27		conduction down	FTCOD(I)	10			HST(I)	HSB(I)
28		reradiation	FTRER(I)	10			HST(I)	HSS
29		convection out	FTCVO(I)	10			HST(I)	HSS
30		conduction up	FTCOU(I)	10			HSB(I)	HST(I)
31		conduction down	FTCDO(I)	10			HSB(I)	HSS
32	Water (W)	precipitation	FTPPT(I)	10			WSS	WSI(I)
33		snow melting/infiltration	FTSNI(I)	10			WSI(I)	WTS(I)
34		evaporation, surface	FTEVS(I)	10			WTS(I)	WSS
35		interlayer infiltration	FTINF(I)	10			WTS(I)	WBS(I)
36		evaporation, topsoil	FTEVU(I)	10			WTS(I)	WSS
37		transpiration, upper soil layer	FTTRU(I)	10			WTS(I)	WSS
38		percolation	FTPER(I)	10			WBS(I)	WGR(I)
39		transpiration, lower	FTTRL(I)	10			WBS(I)	WSS
40		springflow	FTSPF(I)	10			WGR(I)	WSS
41	P	natality, vertebrates, aquatic	FANTV(I)	2			PSS	PAV(I)
42		natality, invertebrates, aquatic	FANTI(I)	2			PSS	PAI(I)
43		mortality, vertebrates, aquatic	FAMRV(I)	2			PAV(I)	PSS
44		mortality, invertebrates, aquatic	FAMRI(I)	2			PAI(I)	PSS
45	K	growth, vertebrates, aquatic	FAGRV(I)	2			GSS	GAV(I)
46		growth, invertebrates, aquatic	FAGRI(I)	2			GSS	GAI(I)
47		respiration, vertebrates, aquatic	FARSV(I)	2			GAV(I)	GSS(I)
48		respiration, invertebrates, aquatic	FARSI(I)	2			GAI(I)	GSS
49	C	photosynthesis, rooted, aquatic	FAPHR(I)	2			CSS	CAR(I)
50		photosynthesis, nonrooted, aquatic	FAPHN(I)	2			CSS	CAN
51		excretion input, aquatic	FAEXC(I)	2			CSS	CAD(I)
52		dead animal input, aquatic	FADED(I)	2			CSS	CAD(I)
53		death, plant, rooted, aquatic (shoot)	FASDR(I)	2			CAR(I)	CAD(I)
54		respiration, rooted, aquatic	FARPR(I)	2			CAR(I)	CSS
55		grazing output, rooted, aquatic	FAGRR(I)	2			CAR(I)	CSS
56		death, nonrooted, aquatic (shoot)	FASDN(I)	2			CAN(I)	CAD(I)
57		respiration, nonrooted, aquatic	FARPN(I)	2			CAN(I)	CSS
58		grazing output, nonrooted, aquatic	FAGRN(I)	2			CAN(I)	CSS
59		decomposition, detritus, aquatic	FADEC(I)	2			CAD(I)	CSS
60		grazing, detritus, aquatic	FAGRD(I)	2			CAD(I)	CSS
61	H	radiation, aquatic	FARAD(I)	2			HSS	HAT(I)
62		convection, aquatic, in	FACVI(I)	2			HSS	HAT(I)
63		conduction down, aquatic	FACOD(I)	2			HAT(I)	HAB(I)
64		reradiation, aquatic	FARER(I)	2			HAT(I)	HSS
65		convection aquatic, out	FACVO(I)	2			HAT(I)	HSS
66		conduction up, aquatic	FACOU(I)	2			HAB(I)	HAT(I)
67		conduction down, aquatic	FACDO(I)	2			HAB(I)	HSS
68	W	precipitation, aquatic	FAPPT(I)	2			WSS	WAI(I)
69		aquatic ice melting water input	FASNI(I)	2			WAI(I)	WAW(I)
70		surface evaporation (ice)	FAEVS(I)	2			WAI(I)	WSS
71		water evaporation, aquatic	FAEVW(I)	2			WAW(I)	WSS
72		transpiration, aquatic	FATRW(I)	2			WAA(I)	WSS
73		stream flow, aquatic	FASTR(I)	2			WAA(I)	WSS
74	P	animal transfer in	FITRI(I,J,K)	9	10	10	PTA(I,K)	PTA(J,K)
75		animal transfer out	FITRO(I,J,K)	10	9	10	PTA(J,K)	PTA(I,K)
76	W	surface water runin	FIWRI(I,J)	9	10		WSI(I)	WSI(J)
77		surface water runout	FIWRO(I,J)	10	9		WSI(J)	WSI(I)
78	C	litter flow in	FILRI(I,J)	9	10		CLA(I)	CLA(J)
79		litter flow out	FILRO(I,J)	10	9		CLA(J)	CLA(I)
80	W	groundwater flow in	FIGWI(I,J)	9	10		WGR(I)	WGR(J)
81		groundwater flow out	FIGWO(I,J)	10	9		WGR(J)	WGR(I)
82	Surface Area of Ecosystem Response Units (A)	deforestation	FIDEP				ACR(1)	ACR(2)
83		rehabilitation	FIRHB(I)	2			ACR(2),ACR(3)	ACR(5),ACR(8)
84		stand establishment	FISTD	2			ACR(5),ACR(8)	ACR(6),ACR(9)
85		flooding	FIFLO				ACR(3)	ACR(11)

*See Table 2-1 for subscript identification.

Table 5-2

ALPHABETIC LISTING OF VARIABLES AND PROCESSES IN THE
TRACT C-b ENVIRONMENTAL SYSTEM

ACRONYM	ITEM	FIRST SUBSCRIPT	SECOND SUBSCRIPT	THIRD SUBSCRIPT	SUBMODEL
ACR (I)	surface area of ecosystem response units	area			AREA (A)
CAD (I)	aquatic detritus	area			
CAN (I)	aquatic nonrooted plants	area			
CAR (I)	aquatic rooted plants	area			
CLA (I)	aboveground litter	area			CARBON (C)
CLB (I)	belowground litter	area			
CSS	carbon source-sink				
CVD (I,J)	standing dead vegetation	area	group		
CVR (I,J)	live roots	area	group		
CVS (I,J)	live shoots	area	group		
DCT	pinyon-juniper clearing (forest cutting schedule)				
DGR	livestock grazing				
DOL (I)	oil shale development-related variables	kind			DRIVING VARIABLES
DPT	precipitation				
DRD	solar radiation				
DTA	air temperature				
DWD	wind				
FACDO (I)	aquatic conduction down	area			H
FACOD (I)	aquatic conduction down	area			H
FACOU (I)	aquatic conduction up	area			H
FACVI (I)	aquatic convection in	area			H
FACVO (I)	aquatic convection out	area			H
FADEC (I)	aquatic detritus decomposition	area			C
FADED (I)	aquatic dead animal input	area			C
FAEVS (I)	aquatic surface evaporation	area			W
FAEVW (I)	aquatic water evaporation	area			W
FAEXC (I)	aquatic excretion input	area			C
FAGRD (I)	aquatic detritus grazing	area			C
FAGRI (I)	aquatic invertebrate growth	area			C
FAGRN (I)	aquatic nonrooted plant grazing	area			C
FAGRR (I)	aquatic rooted plant grazing	area			C
FAGRV (I)	aquatic vertebrate growth	area			C
FAMRI (I)	aquatic invertebrate mortality	area			P
FAMRV (I)	aquatic vertebrate mortality	area			P
FANTI (I)	aquatic invertebrate natality	area			P
FANTV (I)	aquatic vertebrate natality	area			P
FAPHN (I)	aquatic nonrooted plant photosynthesis	area			C
FAPHR (I)	aquatic rooted plant photosynthesis	area			C
FAPPT (I)	aquatic precipitation input	area			W
FARAD (I)	aquatic radiation input	area			H
FARFR (I)	aquatic reradiation out	area			H
FARPN (I)	aquatic nonrooted plant respiration	area			C
FARPR (I)	aquatic rooted plant respiration	area			C
FARSI (I)	aquatic invertebrate respiration	area			C
FARSV (I)	aquatic vertebrate respiration	area			C
FASDN (I)	aquatic nonrooted plant death	area			C
FASDR (I)	aquatic rooted plant death	area			C
FASNI (I)	aquatic ice melting water input	area			W
FASTR (I)	aquatic streamflow	area			W
FATRW (I)	aquatic transpiration	area			W
FIDFF	deforestation				A
FIFLD	flooding				A
FIGWI (I,J)	groundwater flow in	to	from		W
FIGWO (I,J)	groundwater flow out	to	from		W
FILRI (I,J)	litter transfer in	to	from		C
FILRO (I,J)	litter transfer out	to	from		C
FIRHB (I)	rehabilitation	age			A
FISTD	stand establishment				A
FITRI (I,J,K)	animal transfer in	to	from	group	P
FITRO (I,J,K)	animal transfer out	to	from	group	P
FIWRI (I,J)	surface water runin	to	from		W
FIWRO (I,J)	surface water runout	to	from		W
FTABD (I)	decomposition aboveground litter	area			C
FTBED (I)	decomposition belowground litter	area			C
FTCDO (I)	conduction down	area			H
FTCOD (I)	conduction down	area			H
FTCOU (I)	conduction up	area			H
FTCVI (I)	convection in	area			H
FTCVO (I)	convection out	area			H
FTDED (I,J)	dead animal input	area	group		C
FTDES (I,J)	dead shattering	area	group		C
FTEMI (I,J)	emigration	area	group		P
FTEVS (I)	surface evaporation	area	group		W
FTEVU (I)	evaporation, upper soil layer	area			W
FTEXC (I,J)	excretion input	area	group		C
FTGRA (I,J,K)	grazing of litter aboveground	area	p. group	a. group	C
FTGRB (I,J,K)	grazing of litter belowground	area	p. group	a. group	C
FTGRD (I,J,K)	grazing of standing dead	area	p. group	a. group	C
FTGRO (I,J)	animal growth	area	group		C
FTGRR (I,J,K)	grazing of roots	area	p. group	a. group	C
FTGRS (I,J,K)	grazing of shoots	area	p. group	a. group	C
FTIMM (I,J)	immigration	area	group		P
FTINF (I)	interlayer infiltration	area			W
FTMOR (I,J)	mortality	area	group		P
FTNAT (I,J)	natality	area	group		P
FTPER (I)	percolation to groundwater	area			W
FTPHO (I,J)	photosynthesis	area	group		C
FTPPT (I)	precipitation input	area	group		W
FTRAD (I)	radiation input	area			H
FTRER (I)	reradiation	area			H

Table 5-2

(CONTINUED)

FTRES (I,J)	animal respiration	area			G
FTROD (I,J)	root death	area	group		C
FTROR (I,J)	root respiration	area	group		C
FTSHD (I,J)	shoot death	area	group		C
FTSHR (I,J)	shoot respiration	area	group		C
FTSHS (I,J)	shoot shattering	area	group		C
FTSNI (I)	snow melting and infiltration	area	group		W
FTSPF (I)	springflow	area	group		P
FTTRL (I)	transpiration, lower soil layer	area			W
FTTRR (I,J)	translocation to roots	area			C
FTTRS (I,J)	translocation to shoots	area	group		C
FTTRU (I)	transpiration, upper soil layer	area	group		W
GTA (I,J)	terrestrial animal weights	area	group		ANIMAL WEIGHT (G)
GAI (I,J)	aquatic invertebrate weights	area	group		
GAV (I,J)	aquatic vertebrate weights	area	group		
GSS	weight source-sink				
HAB (I)	heat in aquatic bottom layer	area			HEAT (H)
HAT (I)	heat in aquatic top layer	area			
HSB (I)	heat in soil bottom layer	area			
HSS	heat source-sink				
HST (I)	heat in soil top layer	area			
PAI (I)	aquatic invertebrate population	area			POPULATION (P)
PTA (I,J)	population terrestrial animals	area	group		
PAV (I)	aquatic vertebrate population	area			
PSS	population source-sink				
WAI (I)	aquatic ice layer water	area			WATER (W)
WAW (I)	aquatic water	area			
WBS (I)	water in bottom soil layer	area			
WGR (I)	groundwater	area			
WSI (I)	surface water	area			
WSS	water source-sink				
WTS (I)	water in top soil layer	area			

		MOBILE ANIMALS IN AREA										
		1	2	3	4	5	6	7	8	9	10	11
MOBILE ANIMALS IN AREA	1		X	X	X	X	X	X	X	X	X	
	2	X		X	X	X	X	X	X	X	X	
	3	X	X		X	X	X	X	X	X	X	
	4	X	X	X		X	X	X	X	X	X	
	5	X	X	X	X		X	X	X	X	X	
	6	X	X	X	X	X		X	X	X	X	
	7	X	X	X	X	X	X		X	X	X	
	8	X	X	X	X	X	X	X		X	X	
	9	X	X	X	X	X	X	X	X		X	
	10	X	X	X	X	X	X	X	X	X		
	11											
ABOVEGROUND LITTER AND SURFACE WATER IN AREA	1											
	2											
	3											
	4											
	5											
	6											
	7											
	8											
	9											
	10											
	11											
GROUNDWATER IN AREA	1											
	2											
	3											
	4											
	5											
	6											
	7											
	8											
	9											
	10											
	11											
SURFACE ACREAGE IN AREA	1											
	2											
	3											
	4											
	5											
	6											
	7											
	8											
	9											
	10											
	11											

		ABOVEGROUND LITTER AND SURFACE WATER IN AREA											
		1	2	3	4	5	6	7	8	9	10	11	
MOBILE ANIMALS IN AREA	1												
	2												
	3												
	4												
	5												
	6												
	7												
	8												
	9												
	10												
	11												
ABOVEGROUND LITTER AND SURFACE WATER IN AREA	1			X	X				X	X	X		
	2			X	X				X	X	X		
	3											X	X
	4											X	X
	5			X	X				X	X	X		
	6			X	X				X	X	X		
	7			X	X				X	X	X		
	8											X	X
	9											X	X
	10											X	X
	11												
GROUNDWATER IN AREA	1												
	2												
	3												
	4												
	5												
	6												
	7												
	8												
	9												
	10												
	11												
SURFACE ACREAGE IN AREA	1												
	2												
	3												
	4												
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	6												
	7												
	8												
	9												
	10												
	11												

		GROUNDWATER IN AREA											
		1	2	3	4	5	6	7	8	9	10	11	
MOBILE ANIMALS IN AREA	1												
	2												
	3												
	4												
	5												
	6												
	7												
	8												
	9												
	10												
	11												
ABOVEGROUND LITTER AND SURFACE WATER IN AREA	1												
	2												
	3												
	4												
	5												
	6												
	7												
	8												
	9												
	10												
	11												
GROUNDWATER IN AREA	1			X	X				X	X	X		
	2			X	X				X	X	X		
	3											X	X
	4											X	X
	5			X	X				X	X	X		
	6			X	X				X	X	X		
	7			X	X				X	X	X		
	8											X	X
	9											X	X
	10											X	X
	11												
SURFACE ACREAGE IN AREA	1												
	2												
	3												
	4												
	5												
	6												
	7												
	8												
	9												
	10												
	11												

		SURFACE ACREAGE IN AREA										
		1	2	3	4	5	6	7	8	9	10	11
MOBILE ANIMALS IN AREA	1											
	2											
	3											
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	9											
	10											
	11											
ABOVEGROUND LITTER AND SURFACE WATER IN AREA	1											
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	11											
GROUNDWATER IN AREA	1											
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	5											
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	7											
	8											
	9											
	10											
	11											
SURFACE ACREAGE IN AREA	1		X									
	2					X						
	3								X			X
	4											
	5						X					
	6							X				
	7											
	8									X		
	9										X	
	10											
	11											

Figure 5-4 A COUPLING MATRIX FOR FLOWS BETWEEN ECOSYSTEM RESPONSE UNITS OF MOBILE ANIMALS, ABOVEGROUND LITTER AND SURFACE WATER, GROUNDWATER, AND ACREAGE.

Figure 5-5 A CONCEPTUAL MODEL OF HOW THE FIVE FLOW CURRENCIES ARE DISTRIBUTED WITHIN ANY SINGLE ECOSYSTEM RESPONSE UNIT. EACH NUMBERED TRIANGLE REFERS TO A SPECIFIC PROCESS THAT REGULATES A GIVEN FLOW. THE FLOW DYNAMICS OF THE SIXTH FLOW CURRENCY, LAND SURFACE, ARE DIAGRAMMED AT THE BOTTOM OF THE FIGURE.

(Refer to Supplementary Envelope)

Figure 5-6 A HOLISTIC FLOW DIAGRAM OF THE TRACT C-b ENVIRONMENTAL SYSTEM

(Refer to Supplementary Envelope)

For all the complexity the total-system model diagram presents at first glance, continued inspection shows it is essentially made up of repeating units which in themselves are relatively simple in structure. There are 10 repeating terrestrial units and one aquatic unit within the overall system flow diagram (Figure 5-6). All processes and variables within the overall system structure are under the influence or control of the same set of driving variables. Sources and sinks for animal numbers, weights, plant carbon biomass, heat, and water are outside the system boundary.

Further inspection of the overall system diagram shows one compartment with no dynamic characteristics: the surface area of the meadowland. It is assumed in the conceptualization of land flows that this critical habitat will not be modified in the development process, but it is included for completeness of the overall diagram.

Although they are given separate area designations, the different rehabilitation stages on the bottomland sites and the upland sites would only vary slightly due to microclimate. One could expect that the parent material would be similar for both sites, as it would be derived in most instances from rubbled oil shale covered with a mixed top soil. Both systems would also be under intensive management perhaps involving irrigation at least in the first year, fertilization at least in the first two years, and controlled grazing throughout.

The seeming complexity of the names of variables and processes in the model is reducing when one examines the structure of the acronym listing (Table 5-2). All acronyms for flows start with the letter F. All variables within the plant carbon subsystem begin with the letter C, the driving variables D, the aquatic variables W, and appropriate designations for other variables.

5.4 An Effects Matrix for Tract C-b

An effects matrix (Figure 5-7) was developed by utilizing the processes and components from Chapters 2 and 3 and the environmental perturbations associated with oil shale development from Chapter 4. The variables from these sources were combined into effect generator and effect receptor sets. The two sets, 112 effect receptors and 97 effect generators, included all of the variables in the parent sources. These original sets of variables are listed in Appendix D.

The effect receptor set was organized into abiotic, plant, animal, and aquatic processes, abiotic and biotic components and community indices. The effect generator set included driving variables, atmospheric, terrestrial and aquatic perturbations, and abiotic, plant, animal and aquatic system state variables.

Figure 5-7 EFFECTS MATRIX. EFFECT GENERATORS ARE LISTED ACROSS TOP, AND EFFECT RECEPTORS ARE LISTED DOWN THE SIDE.

(Refer to Supplementary Envelope)

Within each of these categories, the variables were arranged in a sequence representing the flow of energy or matter within the unit.

The two sets of variables were used to develop a preliminary effects matrix. This matrix was employed to evaluate the utility of the variables in the sets and to identify areas of duplication, overlap, and omission in the sets of variables and their interactions. For example, one point which became readily evident was that several of the variables represented a level of resolution that was too refined for the general level of the matrix. A uniform level of resolution must exist throughout the matrix. Depending on the degree of refinement with which the variables are subdivided and defined, a complementary level of effect resolution is established for the matrix. Effects may be evaluated at levels ranging from ecosystem to biochemical depending on the level of subdivision of the variables employed. For example, the ecosystem standing biomass, the annual biomass increase of a species, and the CO_2 uptake of an individual leaf are three levels at which productivity can be evaluated. To provide this uniformity in the matrix, a resolution threshold of the community and its associated processes was established for the biotic variables. The level of the general community process was established as the threshold for the abiotic variables. Variables that were similar or which represented levels of refinement below the established thresholds were combined. Examples of some of the variables which were developed utilizing these procedures include plant respiration, litter grazing, aquatic plant photosynthesis, water table changes, soil temperature, and evaporation. Tables 5-3 and 5-4 present the combinations of variables which were produced to help establish a uniform level of resolution, eliminate replication and overlap, and add clarity to the interpretation of the matrix.

Examination of the preliminary effects matrix also revealed several variables that were not initially included, but which deserved consideration. To complement the terrestrial plant growth variable, which was developed by combining several effect receptor variables, an aquatic plant growth variable was added to the effect receptors. Aquatic plant growth is a variable which integrates several physiological processes including the original effect receptor of transpiration. A fluoride emission variable was added to the atmospheric perturbations of the effect generators. Since it is unclear at this time what the potential fluoride emissions may be, the highly phytotoxic nature of gaseous fluoride necessitates its consideration. Since there was no perturbation variable which directly addressed the effects of shale oil extraction on water quality, a variable entitled "altered water quality" was added to the effect generators. This variable covers changes which occur in surface water chemistry as a result of its use,

Table 5-3

COMBINATIONS OF EFFECT RECEPTOR VARIABLES

1. SOLAR RADIATION - Radiation (terrestrial); reradiation (terrestrial); radiation (aquatic); reradiation (aquatic).
2. HEAT CONVECTION - Convection in (terrestrial); convection out (terrestrial); convection in (aquatic); convection out (aquatic).
3. HEAT CONDUCTION, TERRESTRIAL - Conduction up; conduction down; conduction down (sink)
4. HEAT CONDUCTION, AQUATIC - Conduction up; conduction down; conduction down (sink)
5. PRECIPITATION - Precipitation (terrestrial); precipitation (aquatic)
6. EVAPORATION - Evaporation, surface; evaporation, topsoil; evaporation, frozen; evaporation, water.
7. LITTER FLOW - Litter flow in; litter flow out
8. INFILTRATION - Melting infiltration; interflow infiltration
9. STREAMFLOW - Surface water runin; surface water runout; streamflow
10. GROUNDWATER FLOW - Groundwater flow in; groundwater flow out
11. PLANT GROWTH - Nutrient uptake; translocation up; translocation down; transpiration, topsoil; transpiration, lower
12. PLANT RESPIRATION - Shoot respiration; root respiration
13. LITTERGRAZING - Above ground intergrazing; below ground intergrazing
14. REVEGETATION - Rehabilitation; stand establishment
15. LITTER DECOMPOSITION - Above ground decomposition; below ground decomposition
16. MOVEMENT - Immigration; emigration; animal transfer in; animal transfer out
17. AQUATIC PLANT PHOTOSYNTHESIS - Photosynthesis, rooted; photosynthesis, nonrooted
18. AQUATIC PLANT RESPIRATION - Respiration, rooted plants; respiration, nonrooted plants
19. AQUATIC PLANT DEATH - Death, rooted plants; death, nonrooted plants
20. AQUATIC PLANT GRAZING - Grazing rooted plants; grazing nonrooted plants

Table 5-4

COMBINATIONS OF EFFECT GENERATOR VARIABLES

1. SULFUR EMISSIONS - Sulfur emissions; SO_2; H_2S
2. NITROGEN EMISSIONS - Nitrogen emissions; NO; NO_2; NO_x
3. HYDROCARBON EMISSIONS - CH_4; NMHC; THC
4. PARTICULATES, AEROSOLS AND DUST - Particulates and aerosols; fugitive dust
5. TRACE ELEMENT EMISSIONS - Trace element contaminants; arsenic; mercury; selenium
6. STEAM EMISSIONS - Steam emissions; water vapor emissions
7. TRANSMISSION LINES AND PIPELINES - Transmission lines ; pipelines
8. ALTERED SOIL CHEMISTRY - Altered surface chemical composition; altered subsurface chemical composition
9. ALTERED SURFACE WATER FLOWS - Peak flow (flash flooding); downstream flow alterations
10. WATER TABLE CHANGES - Water table alterations; altered aquifers; altered groundwater flow systems
11. LITTER - Aboveground litter; belowground litter
12. UPLAND RECOVERY AREA - Upland recovery stages 1, 2 and 3
13. BOTTOMLAND RECOVERY AREA - Bottomland recovery stages 1, 2 and 3
14. SOIL TEMPERATURE - Top layer heat; bottom layer heat
15. SOIL WATER - Topsoil water; bottomsoil water
16. WATER TEMPERATURE - Aquatic top layer heat; aquatic bottom layer heat
17. AQUATIC PLANTS - Aquatic rooted plants; aquatic nonrooted plants
18. WATER - Surface water; aquatic water

either in the extraction process or supplementary site use, and includes the altered groundwater chemical composition variable from the original effect generators.

Two variables which were in the preliminary matrix were eliminated since they did not fit into the scale of the overall plan for effect evaluation which was developed for the final matrix. The variables which were eliminated were pond area and stream area. A list of the variables utilized in developing the final effects matrix is presented in Table 5-5 and 5-6.

The final effects matrix was developed by utilizing the variables produced by aggregations and additions (as described above) and by utilizing the remaining variables from the preliminary matrix. Mitigation efforts will reduce or eliminate many of the potential effects which the perturbation variables could produce. The effect matrix was constructed to identify these potential effects, even though they may never be fully realized. The effects identified in the matrix represent those effects which may be produced if anticipated control levels are not realized, if control equipment malfunctions occur, or if accidental emissions are produced. The matrix identifies these potential effects and serves as a guide to locating those areas in which monitoring efforts should be directed.

The effects matrix also identifies those direct and indirect effects which occur between effect receptors and generators other than those receptors associated with perturbations. These effects provide insight into the many relationships that exist between the variables. They illustrate that many effect generator variables, in addition to the perturbation variables, interact with effect receptors. These interactions serve to illustrate that many variables can produce net effects on a receptor which are indistinguishable.

Two terms and the related concepts associated with the oil shale development variables should be clarified at this point. An environmental perturbation, as defined earlier, is a driving variable consisting of a disturbance that occurs in an environmental system. Most such disturbances are abiotic and it is through time that they affect the biota. An environmental impact, however, implies a receptor, biotic or abiotic, to express an effect. In an environmental system, then, an environmental impact is the observable effect of one or more perturbations to the system. (Note that the definition contains no value judgements, e.g., positive or negative impacts; an impact is simply a change generated by a perturbation.)

Perturbations can be classified as active or passive. An active perturbation is the dynamic direct result of some activity;

it is dynamic in that it moves through time or space. A passive perturbation is static in that it does nothing; it simply is. Emissions of any type that are injected into the environmental system are active; buildings or other structures are passive. A smokestack is considered passive: it impedes the wind; it casts a shadow. When it emits pollutants, those emissions are active because they are the result of an activity, in this case, some process.

The general criterion applied to identifying effects was: do the generator and receptor interact in either a direct or indirect manner to produce a measurable change in the receptor's parameters? The nature of the effect was identified in the matrix through the use of a symbol:

● - indicates a direct effect

◇ - indicates an indirect effect

◆ - indicates that both direct and indirect effects occur.

The nature of the variable interactions, direct or indirect, does not provide an indication of the magnitude of the effect. To provide some insight into the potential ecological magnitude of an effect, a highlight has been applied to those which may be of particular concern. It should be remembered that these effects are of potential concern under the conditions listed earlier and that the mitigation processes which will be in effect may completely eliminate them.

5.5 Component-Process Relationships

Just as each flow is controlled by one or more environmental system processes, so each process is controlled by one or more system components. If this were not the case, each process and each flow would be constant over time. Table 5-7 lists the numbers of variables that affect different processes. Most of the flows are affected by four or fewer driving variables and four or fewer state variables. The table also succinctly points out the interconnectedness of processes and components.

Each process can have several factors affecting it, and the relationship between a factor and the process rate may be linear or nonlinear, direct or indirect, or, in some instances, stepwise. In several cases for nonlinear relationships there are threshold levels of the variable with respect to its effect on the process rate. The functional forms may be increasing or decreasing but generally are one of the following types: linear, concave or convex curvilinear with a maximum, curvilinear with an asymptote parallel to the ordinate or the absciscа, exponential, logarithmic, or discontinuous. In a few instances the functional form may be sinusoidal. These relationships are shown in Figures 5-8 through 5-20. They are grouped by appropriate blocks of processes having

Table 5-5

EFFECT RECEPTOR PROCESSES AND COMPONENTS, WITH ACRONYMS

ABIOTIC PROCESSES

SOLAR RADIATION - FTRAD, FTRER, FARAD, FARER

HEAT CONVECTION - FTCOI, FTCOO, FACOI, FACOO

HEAT CONDUCTION, TERRESTRIAL - FTCOU, FTCOD, FTCDO

HEAT CONDUCTION, AQUATIC - FACOU, FACOD, FACDO

PRECIPITATION - FTPPT, FAPPT

EVAPORATION - FTEVS, FTEVU, FAEVS, FAEVW

MELTING - FASNI

INFILTRATION - FTSNI, FTINF

PERCOLATION - FTPER

RUNOFF - FIWRI, FIWRO

STREAMFLOW - FASTR

SPRINGFLOW - FTGRV

FLOODING - FIFLD

GROUNDWATER FLOW - FIGWI, FIGWO

LITTER - FILRI, FILRO

WEATHERING (GEOLOGIC) -

BIOTIC PROCESSES - PLANT

GERMINATION AND PHENOLOGY -

PHOTOSYNTHESIS - FTPHO

PLANT RESPIRATION - FTSHR, FTROR

PLANT GROWTH - FTTRS, FTTRR, FTTRV, FTTRL

SHOOT DEATH - FTSHD

SHOOT GRAZING - FTGRS

*SHOOT SHATTERING - FTSHS

Table 5-5
(CONTINUED)

ROOT DEATH - FTROD

ROOT GRAZING - FTGRR

DEAD GRAZING - FTGRD

LITTER GRAZING - FTGRA, FTGRB

*DEAD SHATTERING - FTDES

DEFORESTATION - FIDEF

REVEGETATION - FIRHB, FISTD

INTERCEPTION OF PRECIPITATION -

LITTER DECOMPOSITION - FTABD, FTBED

BIOTIC PROCESSES - ANIMAL

NATALITY - FTNAT

MORTALITY - FTMOR

ANIMAL GROWTH - FTGRO

RESPIRATION - FTRES

*REPRODUCTION -

MOVEMENT - FTIMM, FTEMI, FITRI, FITRO

PREDATION -

FOOD SELECTION -

EXCRETION INPUT - FTEXC

DEAD ANIMAL INPUT - FTDED

BIOTIC PROCESSES - AQUATIC

AQUATIC PLANT PHOTOSYNTHESES - FAPHR, FAPHN

AQUATIC PLANT RESPIRATION - FARPR, FARPN

AQUATIC PLANT DEATH - FASDR, FASDN

AQUATIC PLANT GRAZING - FAGRR, FAGRN

Table 5-5

(CONTINUED)

AQUATIC PLANT GROWTH - FATRW

*REPRODUCTION (AQUATIC BIOTA) -

NATALITY, VERTEBRATE - FANTV

GROWTH, VERTEBRATE - FAGRV

RESPIRATION, VERTEBRATE - FARSV

MORTALITY, VERTEBRATE - FAMRV

NATALITY, INVERTEBRATE - FANTI

GROWTH, INVERTEBRATE - FAGRI

RESPIRATION, INVERTEBRATE - FARSI

MORTALITY, INVERTEBRATE - FAMRI

PREDATION -

FOOD SELECTION -

EXCRETION INPUT - FAEXC

DEAD ANIMAL INPUT - FADED

DETRITUS DECOMPOSITION - FADEC

GRAZING DETRITUT - FAGRD

COMPONENTS - ABIOTIC

AIR QUALITY -

AIR TEMPERATURE -

PRECIPITATION -

RELATIVE HUMIDITY -

SOIL PERMEABILITY / WATER CAPACITY -

SOIL MOISTURE -

SOIL CHEMISTRY AND pH -

SOIL TEMPERATURE -

WATER QUALITY -

Table 5-5

(CONTINUED)

COMPONENTS - BIOTIC

INDICATOR SPECIES (AUTOTROPHS)

*PLANT TISSUE -

INDICATOR SPECIES (HETEROTROPHS) -

*ANIMAL TISSUE -

GENERAL HABITAT -

LITTER AND DETRITUS -

INDICES

DIVERSITY INDICES -

COMMUNITY COMPOSITION -

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* These are further defined in the glossary of the User's Reference, Appendix F.

Table 5-6

EFFECT GENERATOR VARIABLES

DRIVING VARIABLES

TIME - T

PRECIPITATION - DPT

AIR TEMPERATURE - DTA

WIND - DWD

SOLAR RADIATION - DRD

PINYON- JUNIPER CLEARING - DCT

LIVESTOCK GRAZING - DGR

HUNTING AND RECREATION - DOL (9)

PERTURBATIONS - ATMOSPHERIC

SULFUR EMISSIONS - DOL(1)

NITROGEN EMISSIONS - DOL (2)

OZONE AND OXIDANT EMISSIONS - DOL(3)

FLUORIDE EMISSIONS

CO EMISSIONS - DOL(5)

HYDROCARBON EMISSIONS -

*PARTICULATES, AEROSOLS AND DUSTS - DOL(7)

TRACE ELEMENT CONTAMINANTS - DOL(4)

FOG -

ICE -

STEAM EMISSIONS - DOL(6)

ODOR -

NOISE AND ACTIVITY - DOL(8)

PERTURBATIONS - TERRESTRIAL

DISTURBED VEGETATION -

UNREVEGETATED BARE AREAS -

Table 5-6

(CONTINUED)

TRANSMISSION LINES AND PIPELINES -

INCREASED ROAD KILLS -

ROADS AND PAVED SURFACES -

UNPAVED ROADS -

BARRIERS (FENCES, CULVERTS, ETC.)

LANDSLIDES -

CHANGES IN CONTOUR -

EROSION -

GROUND SUBSIDENCE -

COMPACTION -

MIXED SOIL PROFILE -

ALTERED HUMUS CONTENT -

ALTERED SOIL CHEMISTRY -

LANDFILLS -

*SHRINK/SWELL CLAYS -

PERTURBATIONS - AQUATIC

SEDIMENTATION -

ALTERED SURFACE WATER FLOWS -

ALTERED STREAM CHANNELS -

ALTERED SURFACE DRAINAGE PATTERNS -

WATER TABLE ALTERATIONS -

ALTERED WATER QUALITY -

*IMPOUNDMENTS -

*SEEPAGE -

EVAPORATION -

Table 5-6

(CONTINUED)

SYSTEM STATE VARIABLES - PLANT

LIVE SHOOTS - CVS

LIVE ROOTS - CVR

STANDING DEAD - CVD

LITTER - CLA, CLB

MEADOW AREA - ACR(4)

UPLAND FOREST AREA - ACR(1)

UPLAND NONFOREST AREA - ACR(2)

GENERAL BOTTOMLAND AREA - ACR(3)

UPLAND RECOVERY STAGES - ACR(5), ACR(6), ACR(7)

BOTTOMLAND RECOVERY STAGES - ACR(8), ACR(9), ACR(10)

SYSTEM STATE VARIABLES - ANIMAL

TERRESTRIAL ANIMAL NUMBERS - PTA

TERRESTRIAL ANIMAL WEIGHTS - GTA

SYSTEM STATE VARIABLES - ABIOTIC

SOIL TEMPERATURE - HST, HSB

WATER TEMPERATURE - HAT, HAB

SOIL WATER - WTS, WBS

GROUNDWATER - WGR

SYSTEM STATE VARIABLES - AQUATIC

AQUATIC VERTEBRATE NUMBERS - PAV

AQUATIC INVERTEBRATE NUMBER - PAI

AQUATIC VERTEBRATE WEIGHT - GAV

AQUATIC INVERTEBRATE WEIGHT - GAI

AQUATIC PLANTS - CAR, CAN

AQUATIC DETRITUS - CAD

Table 5-6

(CONTINUED)

WATER - WST, WAW

*AQUATIC SURFACE LAYER - WAI

*These are further defined in the glossary of the User's Reference, Appendix F.

Table 5-7

INSTANCES IN WHICH A GIVEN NUMBER OF VARIABLES AFFECT A SINGLE PROCESS

	Number of Instances	
Number of Variables Affecting a Process	Driving Variables	State Variables
0	28	4
1	8	14
2	23	29
3	6	3
4	12	16
5	7	1
6	0	5
7	1	4
8	0	4
9	0	4
10	0	0
11	0	1
12	0	2
	85	85

somewhat similar controlling influences, or else blocks of processes in the same subsystem. These relationships are only general in nature and are not quantified in the present case. Quantification of these functional forms would be required to implement a numerical simulation model of the C-b Tract system. The functional forms are put forward here to guide reasoning for cause-effect relationships within the system and for use in subsequent flow-control diagrams. In these figures, the processes have the same numbers as were used in previous tables and figures of this chapter. The variables are given in the same acronyms as were used previously.

5.5.1 Animal Number Flows

Immigration, emigration, and transfer flows (Figure 5-8) are considered together because they are similar. Frequently they differ only in direction, or in the source, or in the sink. Several of the animals have a definite seasonal immigration and emigration pattern. These are illustrated by concave curvilinear functions of time with maxima. For example, many organisms would have an inflow during the spring and outflow during the fall. The points of maxima in these concave curvilinear functions vary with different organism groups.

Several driving variables influence immigration and emigration and transfer flows. Since immigration in the terrestrial submodel includes natality and since arthropods are one of the animal groups, the flow of animals into the system could be expected to be an increasing sigmoid function of temperature (DTA). In a similar manner, some flows out of the system, i.e., emigration flows, would be an inverse sigmoid relationship to temperature.

Livestock grazing is controlled by man and thus is one of the driving variables in the system model (DGR). Flows in and out would essentially on-off switches here.

Two oil shale development-related driving variables, noise and activity disturbance--DOL(8)--and hunting and recreation--DOL(9)--could affect the movement of animals into and out of the system. It is assumed these are linear relationships.

Several system state variables influence immigration, emigration, and transfer of animals from the terrestrial ecosystem response units. The surface water compartment (WSI) represents snow cover for much of the year. Depending upon the ecosystem response unit in which the deep snow occurred, it would cause immigration or emigration. Animals will migrate into or out of specific areas depending upon the availability of food. Perhaps this migration is more controlled by the live vegetation than by other categories; thus live shoot biomass--CVS(I,J)--influences emigration and

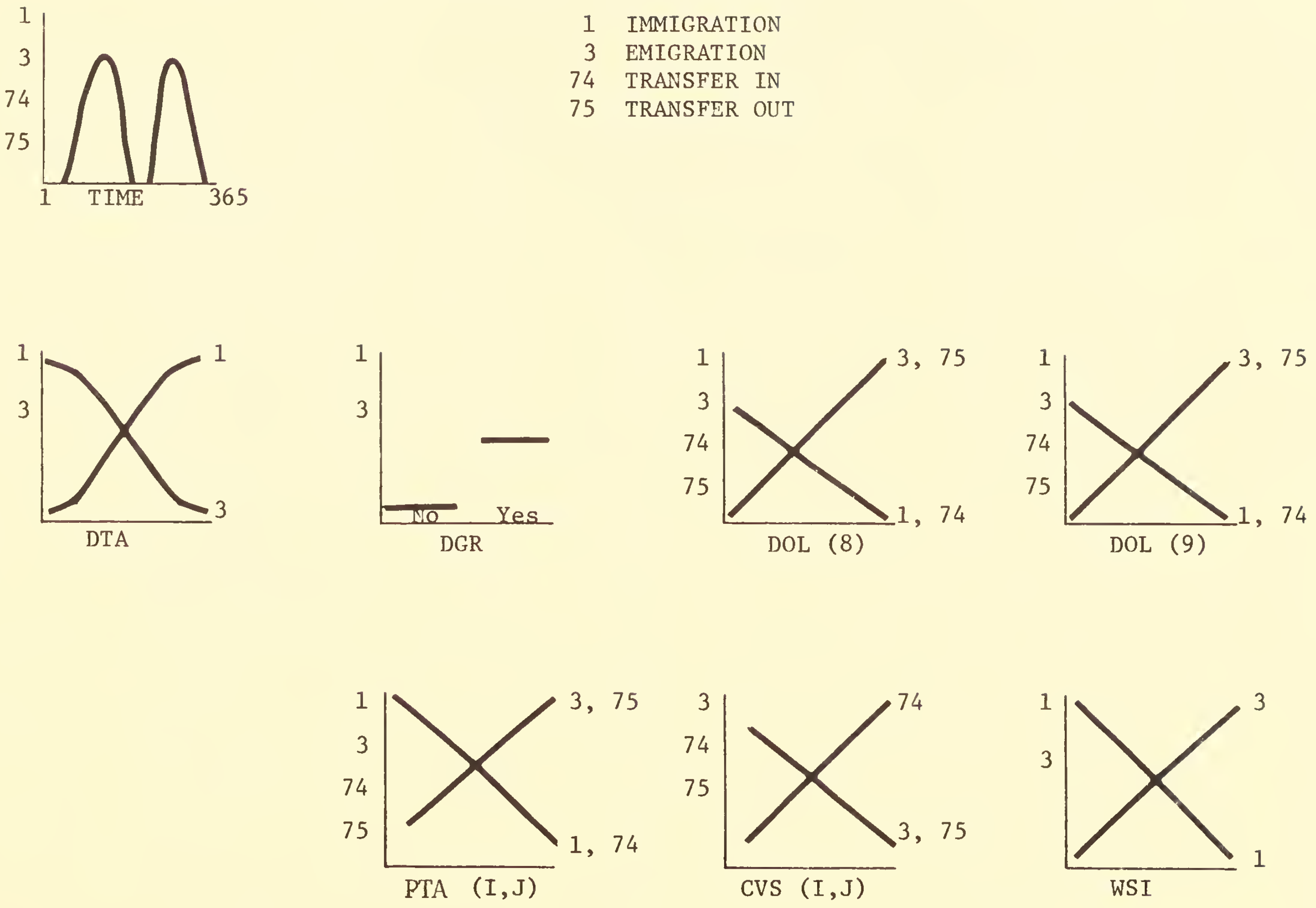


Figure 5-8 FACTORS AFFECTING FLOWS OF ANIMAL POPULATIONS (PROCESSES 1, 3, 74, and 75).

transfers. Some animals are affected by the presence of high populations of the same species or of other species so animal population numbers--PTA(I,J)--would influence the movement of animals in or out of a particular ecosystem response unit.

5.5.2 Growth and Respiration

Relational diagrams for factors affecting growth and respiration flows are illustrated in Figure 5-9. Several driving variables influence growth and respiration flows including air temperature (DTA), trace metal contaminants DOL(4) , carbon monoxide emissions DOL(5) , fugitive dust DOL(7) , and noise and activity disturbance DOL(8) .

Both vertebrate and invertebrate aquatic organisms are shown to grow as a logarithmic increasing function of time.

Growth and respiration of some terrestrial organisms are effectively curvilinear increasing functions of DTA with an asymptote at DTA equal to a lethal temperature. At that point there is a discontinuity; growth and respiration then drop to zero. Little information is available regarding oil shale development driving variables and their relationship to the processes. However, several growth processes can be considered linearly decreasing functions of DOL(4), DOL(5), and DOL(8). Growth of several animals would be a decreasing linear function of concentrations of pollutants. Trace metal contaminants would affect animals in both terrestrial and aquatic subsystems, but carbon monoxide emissions and noise and activity disturbances probably would only influence terrestrial animals. Fugitive dust in the air and in the runoff water could be important in influencing growth and respiration of aquatic animals. Here we assume fugitive dust to have an exponentially increasing impact on respiration and an exponentially decreasing impact on growth.

Several system state variables could affect the growth of terrestrial animals in different ways. Growth would be a linearly increasing function of PTA(I,J), a logarithmically increasing function of GTA(I,J), a logarithmically increasing function of the vegetation biomass, an exponentially increasing function of heat in the different soil layers, and an exponentially increasing function of water in the different soil layers for certain animal groups. Similar relationships would hold for the aquatic subsystem.

Few data are available to quantify these functions at present. Relatively good data are available, however, for the respiration relationship to body weight. For many mammals there is a logarithmically increasing relationship between carbon respired daily to carbon biomass per individual. This is often referred to as the

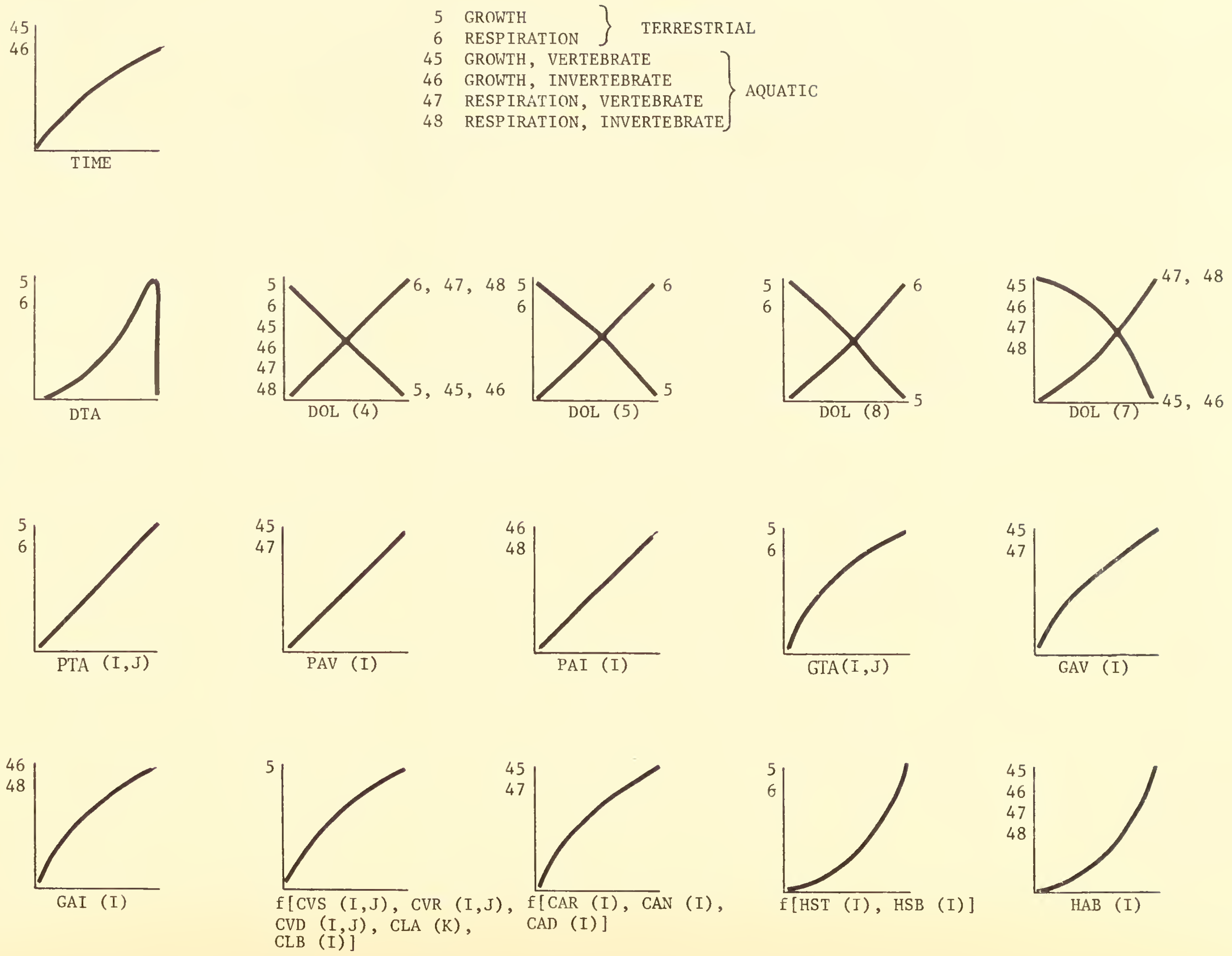


Figure 5-9 FACTORS AFFECTING GROWTH AND RESPIRATION OF TERRESTRIAL AND AQUATIC ANIMALS (PROCESSES 5, 6, 45, 46, 47, 48).

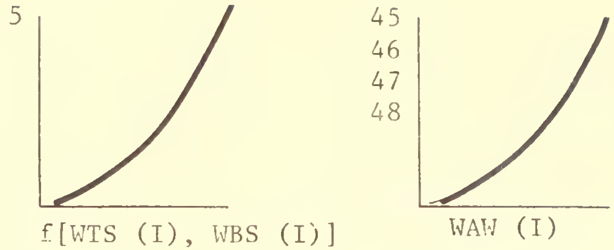


Figure 5-9 FACTORS AFFECTING GROWTH AND RESPIRATION OF TERRESTRIAL AND AQUATIC ANIMALS (PROCESSES 5, 6, 45, 46, 47, and 48) (CONTINUED).

$W^{0.75}$ law. For many aquatic organisms there is a more complex relationship of respiration to temperature than is shown in Figure 5-9. Over a range of approximately 0 to about 30°C respiration is a linear decreasing function of temperature, at about 30 to 40°C respiration rate remains constant, and above 40°C it is an exponentially increasing function until lethal temperature is reached.

5.5.3 Grazing and Excretion Inputs

Three driving variables and seven system state variables or groups of variables are considered to influence grazing flows and excretion input in the conceptual model (Figure 5-10).

Grazing of shoots, standing dead, and litter for several organisms will be a decreasing linear function of precipitation. Many of the birds, arthropods, and reptiles, and large mammals (to some degree) decrease their foraging at times of high precipitation. Snow cover has a linearly decreasing influence on grazing rate of several herbivores of the Tract C-b system. Both air temperature and wind have a logarithmically decreasing influence on feeding rate for several aboveground herbivores.

For many calculation procedures, the amount of forage grazed will be directly proportional to the number of animals present PTA(I,J) . Grazing is dependent upon herbage being available. There is a logarithmic increasing dependence of grazing rate on herbage availability as measured in various plant categories for large herbivores or for arthropods. Many of the arthropods are poikilothermic organisms and thus their grazing rate is an exponentially increasing function of temperature of the soil layers. Forage intake rate, at least for the mammals, is a logarithmically increasing function of individual body weight.

5.5.4 Plant Carbon Flows

Major flows of plant carbon in the system are through the biotic processes of photosynthesis, respiration of shoots and roots, shoot and root death, and decomposition of aboveground and belowground litter. Equivalent flows occur in the aquatic system. Factors influencing these processes are shown in Figure 5-11.

Photosynthesis is influenced in this conceptualization by a large number of variables including DTA, DRD, DOL(1), DOL(2), DOL(3), DOL(4), DOL(6), HST(I), HSB(I), WTS(I), and WBS(I). Photosynthesis is a concave curvilinear function with maxima for both DTA and DRD; a linearly decreasing function of DOL(1), DOL(3), and DOL(4); an increasing linear function of DOL(6); an

8 EXCRETION INPUT TERRESTRIAL
14 SHOOT GRAZING
18 ROOT GRAZING
20 STANDING DEAD GRAZING
22 LITTER GRAZING, ABOVE
24 LITTER GRAZING, BELOW

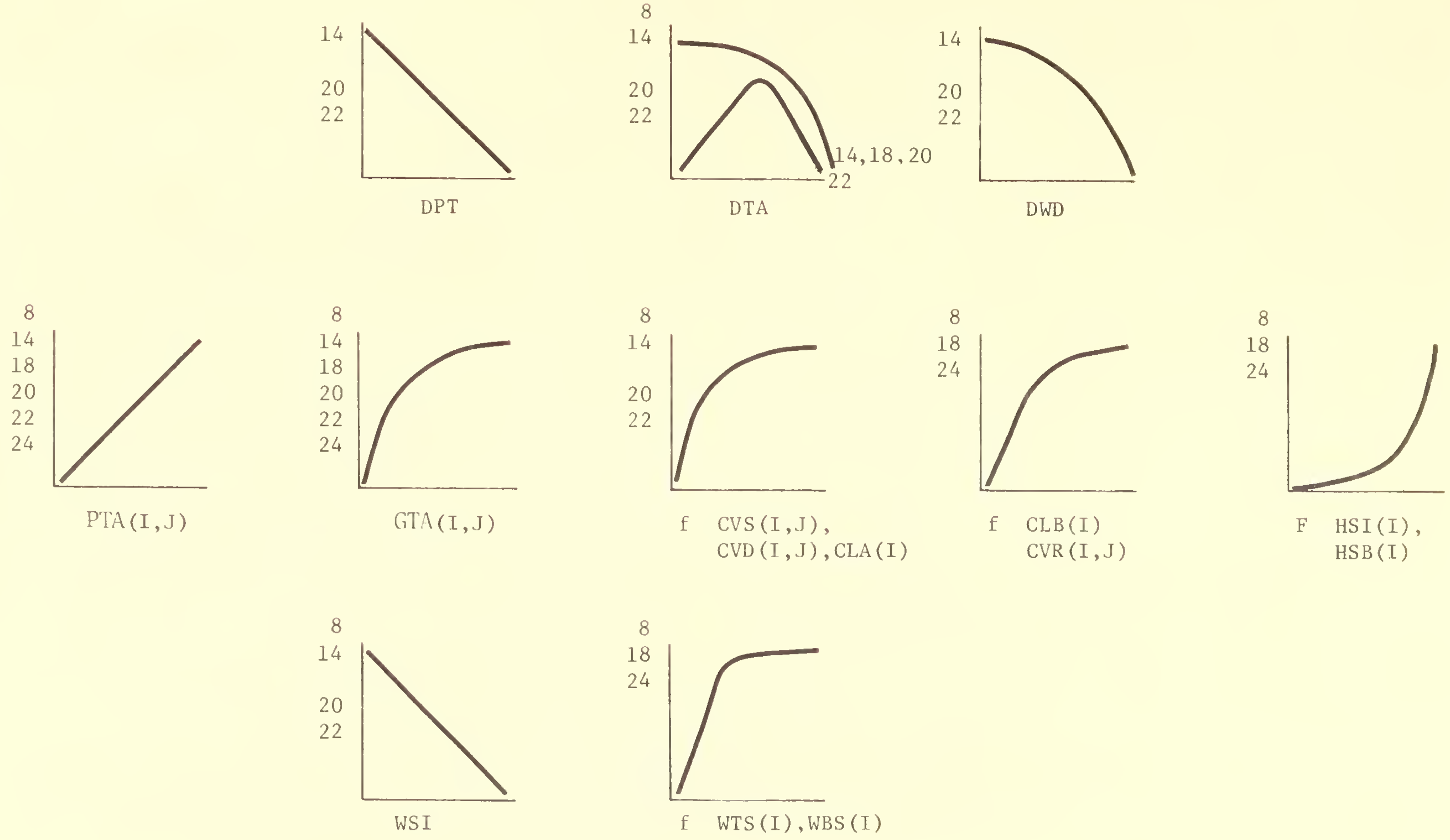


Figure 5 - 10 FACTORS AFFECTING TERRESTRIAL EXCRETION INPUTS AND SHOOT, ROOT, STANDING DEAD, AND LITTER GRAZING (PROCESSES 8, 14, 18, 20, 22, and 24).

7	PHOTOSYNTHESIS, TERRESTRIAL
13	SHOOT RESPIRATION
17	ROOT RESPIRATION
21	ABOVEGROUND DECOMPOSITION
11	SHOOT DEATH
16	ROOT DEATH
49, 50	PHOTOSYNTHESIS, AQUATIC
54, 57	RESPIRATION, AQUATIC
53, 56	DEATH AQUATIC PLANTS
59	DETRITUS DECOMPOSITION

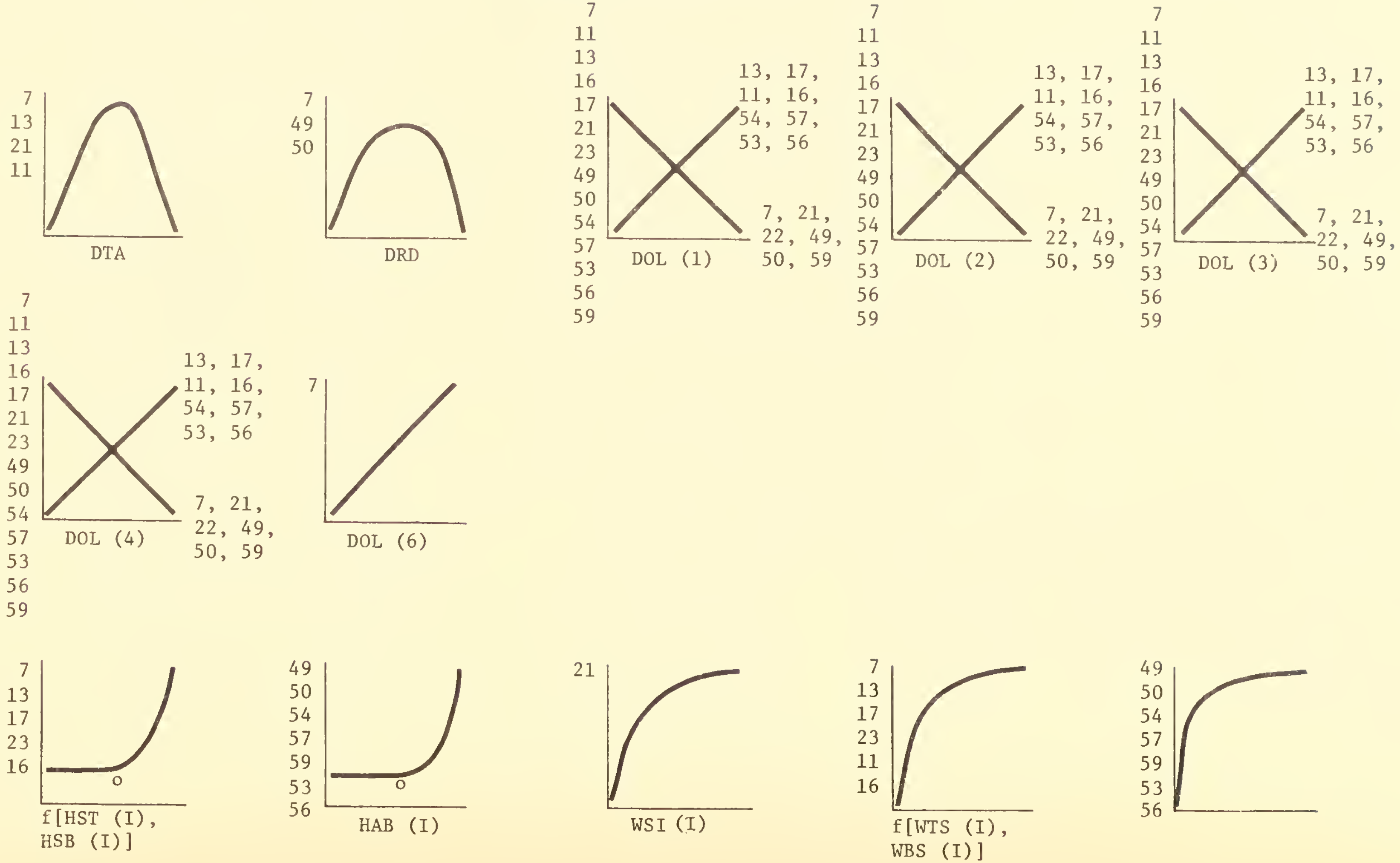


Figure 5-11 FACTORS AFFECTING PHOTOSYNTHESIS AND RESPIRATION OF PLANTS AND DECOMPOSITION OF LITTER AND DETRITUS IN TERRESTRIAL AND AQUATIC SYSTEMS (PROCESSES 7,11, 13, 16, 17, 21, 23, 49, 50, 53, 54, 56, 57, and 59).

increasing exponential function of HST, HSB, and HAB for temperature in ^{o}C; and a logarithmically increasing function of WTS(1) and WBS(1).

Many of the same oil shale development pollutant emission factors affect aboveground decomposition, photosynthesis of aquatic plants, and aquatic detritus decomposition that influence photosynthesis of terrestrial plants.

Although respiration and photosynthesis are affected in a similar manner by manner by DTA, HST, HSB, WSI, WTS, and WBS, the relationship of respiration to oil shale development pollutants is the inverse of the relationship to photosynthesis.

5.5.5 Terrestrial Heat Flows

Radiation, convection, and conduction are the basic heat flow processes in both the terrestrial and aquatic ecosystems. Relational diagrams for terrestrial heat flows are shown in Figure 5-12. In calculating a heat flow,a difference is taken between the temperature of two exchanging bodies. Thus the functional relationships show coupled sets of variables. The functional relations are exponentially increasing or exponentially decreasing in form. Heat generally flows as a 4th power function of the difference in temperatures between the two exchanging bodies.

5.5.6 Aquatic Grazing and Excretion Inputs

Most of the aquatic herbivores are poikilothermic, but they live in a medium with relatively constant temperature. Thus temperature is not represented in the simplified conceptualization of functional relationships shown in Figure 5-13.

Excretion rates follow grazing rates throughout this conceptualization. Grazing rates increase linearly according to the population density of vertebrate and invertebrate aquatic grazers, increase logarithmically with biomass per individual, increase logarithmically with food availability CAR(I), CAN(I), CAD(I) , increase exponentially with changes in water temperature, and show a sigmoid relationship to water volume. The sigmoid relationship presumes that as the water volume increases, the grazing rate initially shows an exponential increase because much more habitat becomes available. With further increases in water volume, however, there is a logarithmic increase of grazing rate because the food becomes "diluted" in the environment of the grazer.

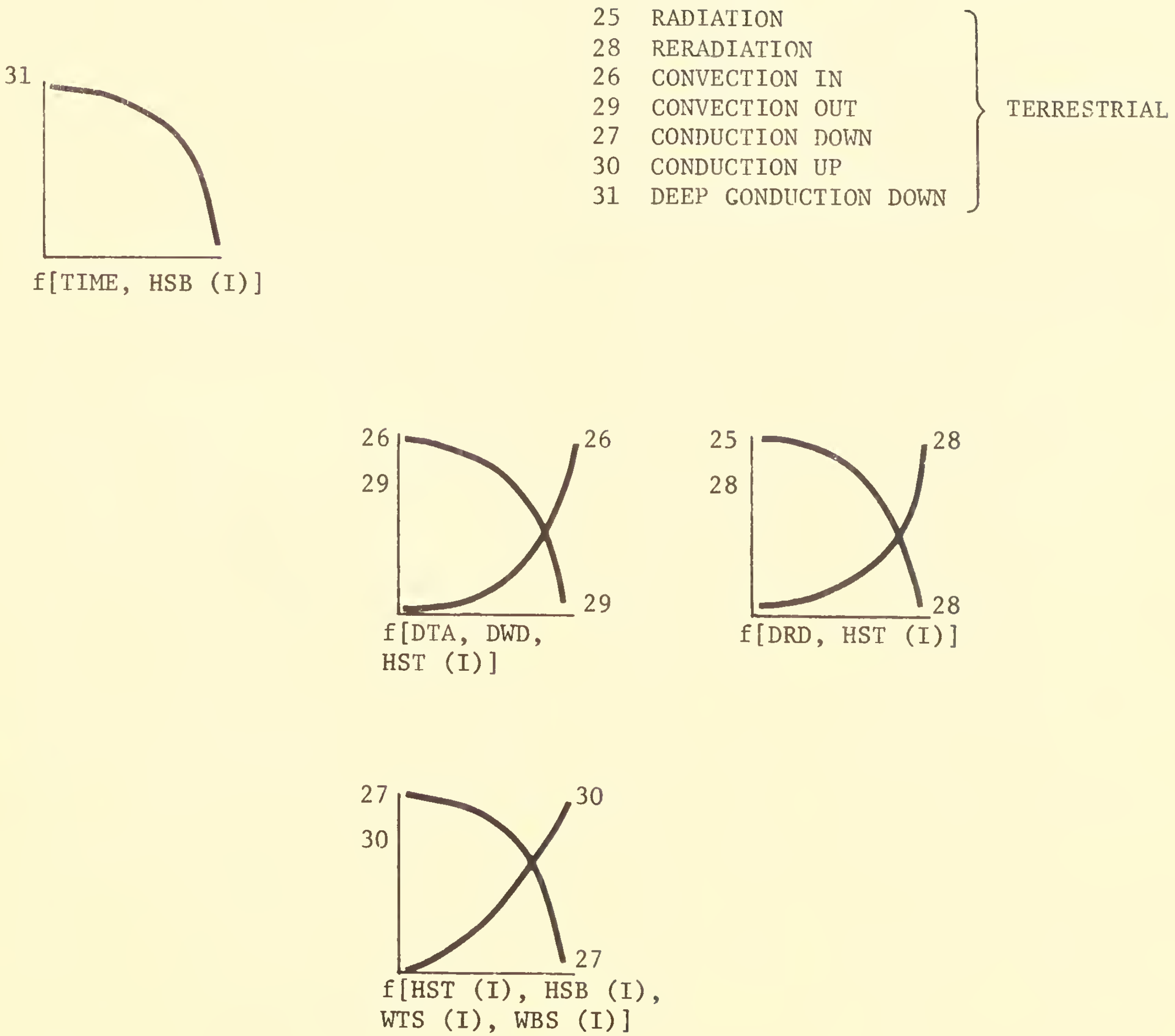


Figure 5-12 FACTORS AFFECTING HEAT FLOWS IN TERRESTRIAL SUBSYSTEMS (PROCESSES 25, 26, 27, 28, 29, 30, and 31).

51	EXCRETION INPUT AQUATIC
55	GRAZING AQUATIC ROUTED
58	GRAZING AQUATIC NONROOTED
60	GRAZING AQUATIC DETRITUS

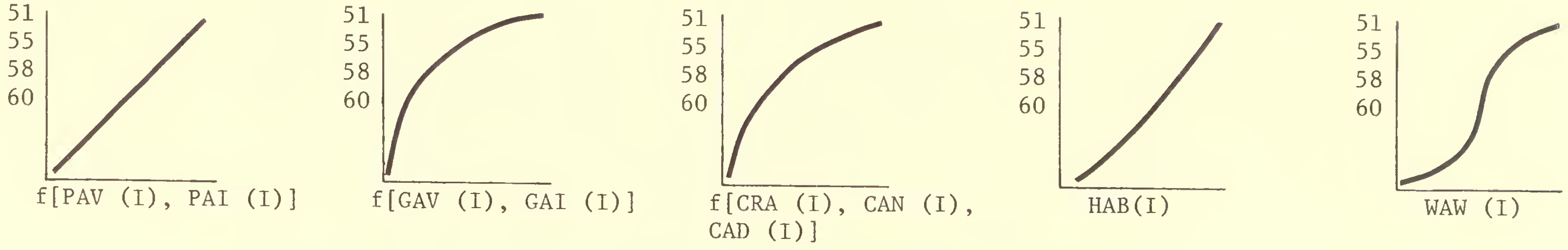


Figure 5-13 FACTORS AFFECTING EXCRETION INPUT AND GRAZING IN THE AQUATIC SUBSYSTEM (PROCESSES 51, 55, 58, and 60).

5.5.7 Aquatic Heat Flows

Aquatic heat flows, shown in Figure 5-14, are conceptually simpler than terrestrial heat flows. However, they follow the same general approach, i.e., that of looking at temperature of source and receiving compartments and using a logarithmically increasing or decreasing functional relationship in the calculation.

The relationship of time to heat flow in both Figure 5-12 and 5-14 needs clarification. The exchange here in the terrestrial situation is between the lower soil layer and the parent bedrock. In the aquatic situation it is between the water and the streambed. It is presumed that the temperature of the bedrock or of the streambed can be approximated by a function of time since there is no compartment for these variables within the conceptual model. Therefore, one takes the difference between temperature of a compartment in the system and of a "pseudo-compartment" which is represented as a function of time.

5.5.8 Terrestrial Water Flows

There are numerous water flows in the model as conceptualized, and relational diagrams for these are shown in Figure 5-15. There is a dominance of linear relationships.

The precipitation inputs to the terrestrial and the aquatic system are defined by a flow entitled "precipitation." Unfortunately, this is also the name of one of the driving variables. The form of precipitation input depends also on temperature. Thus separate parallel increasing linear functions show the relationship of the precipitation flow rate to the driving variables precipitation and temperature in first graph of Figure 5-15.

The melting or infiltration flow depends first on temperature being above 0°C at the soil surface. Then it depends upon the amount of snow or water to infiltrate and also on the air temperature. In general, evapotranspiration flows from the surface and from the topsoil are increasing linear functions of air temperature and wind, but they are decreasing linear functions of aboveground vegetation biomass. Evaporation rate from the top soil layer is a linearly increasing function of temperature and moisture content of that soil layer in the present conceptualization. The relationship between evaporation of surface water (generally snow) or (WSI), is curvilinear with an asymptote when there is enough snow to cover the total soil surface. Infiltration into and through the soil layers is dependent upon temperatures being above 0°C.

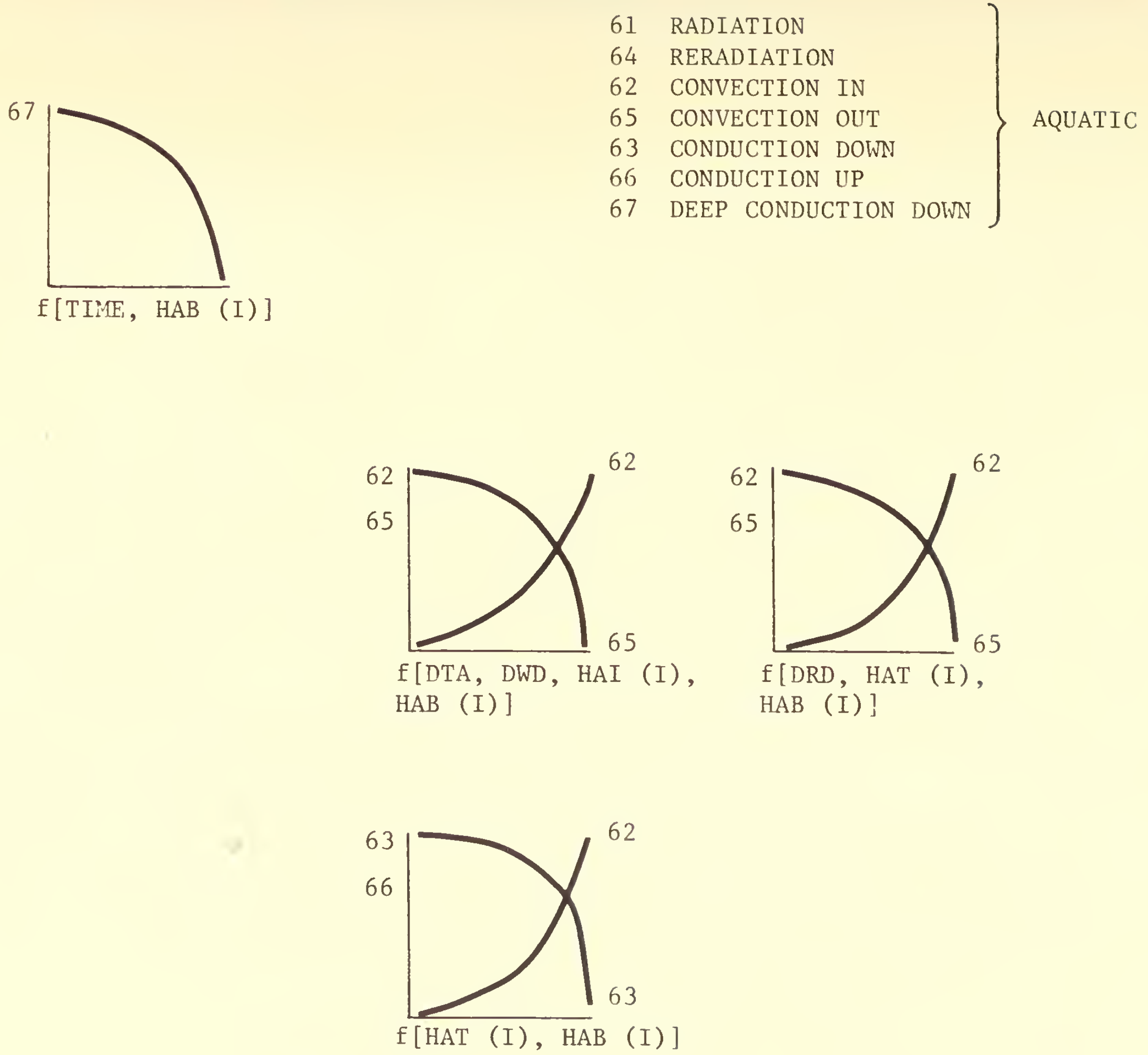


Figure 5-14 FACTORS AFFECTING HEAT FLOWS IN THE AQUATIC SUBSYSTEMS (PROCESSES 61, 62, 63, 64, 65, 66, and 67).

32, 68	PRECIPITATION
33	MELTING/INFILTRATION
69	MELTING - AQUATIC
34	EVAPORATION, SURFACE
36	EVAPORATION, TOP SOIL
35	INTERFLOW INFILTRATION
38	PERCOLATION
40	SPRINGFLOW

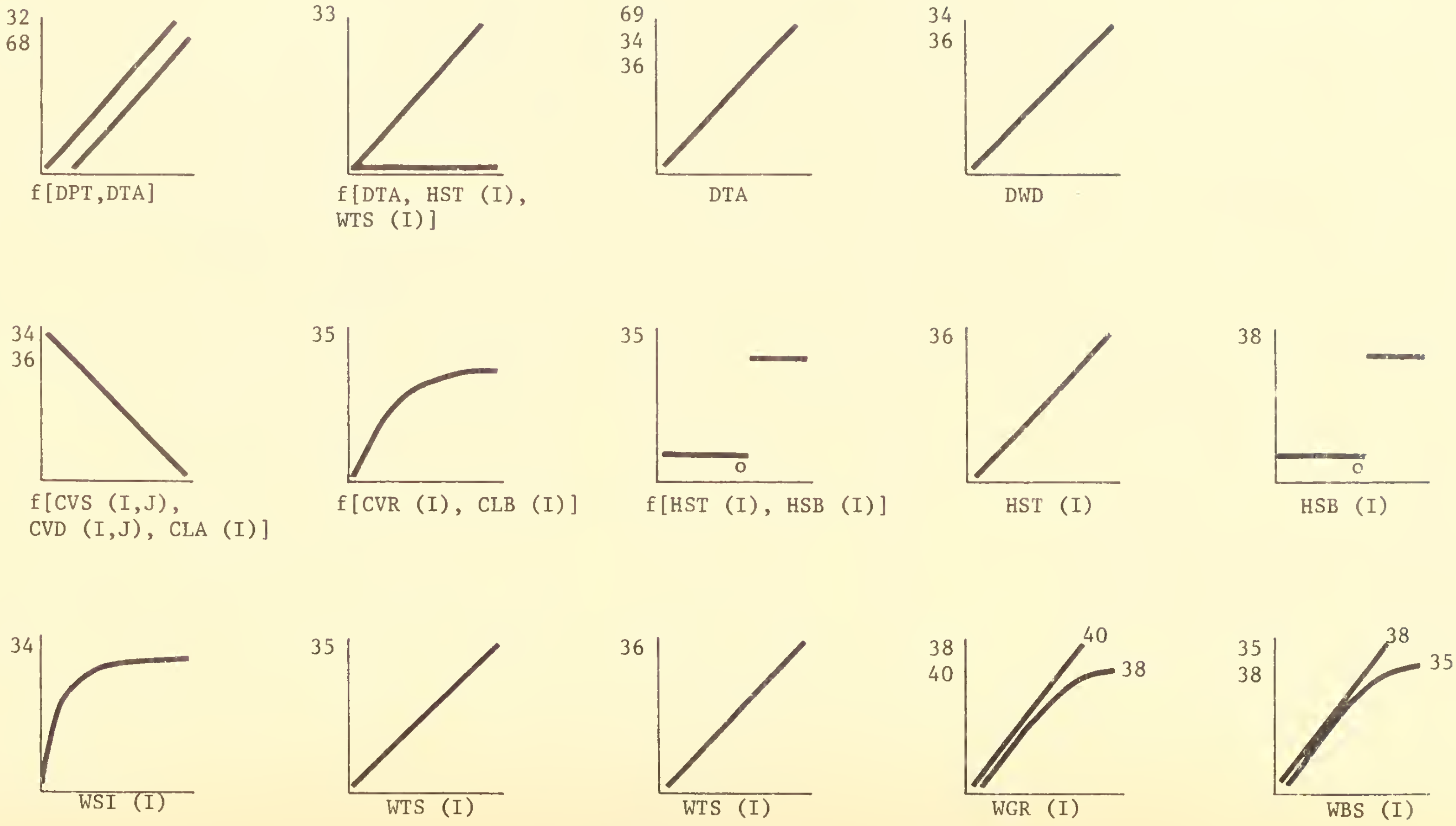


Figure 5-15 FACTORS AFFECTING WATER FLOWS WITHIN THE TERRESTRIAL SUBSYSTEMS (PROCESSES 32, 33, 34, 34, 35, 36, 38, 40, 68, and 69).

Additional water flows are illustrated in relational diagrams of Figure 5-16. Evaporation from aquatic surfaces is affected by temperature and wind in an increasing linear manner as it is in the terrestrial soil surface. Flows of water across the surface from one ecosystem response unit to another are a decreasing linear function of amount of surface water and decreasing logarithmic functions of standing crop biomass of vegetation.

Transpiration flows and groundwater flows are illustrated in Figure 5-17. Transpiration in terrestrial and aquatic systems is a linear increasing function of temperature, wind, and solar radiation. Transpiration of water from the soil depends upon temperature being above $0^{o}C$ and then it becomes an exponentially increasing function. Water content of the soil shows a curvilinear relationship to transpiration rate with an asymptote at some point prior to field capacity. Transpiration by aquatic plants is dependent upon free water being available. Then transpiration is a curvilinear function with an asymptote at a water volume, after which water surface does not change appreciably.

Little is known of alluvial flow systems in Tract C-b so the functional relationship for groundwater movement in and out of a particular ecosystem response unit shown in Figure 5-17 is only hypothetical. It is assumed that there is a slight exponentially increasing function for groundwater flow out and a slight logarithmically increasing function for groundwater flow in.

5.5.9 Resource Management-Controlled Surface Area Flows

Deforestation, rehabilitation, stand establishment, and flooding are considered here as resource management-controlled surface area flows and are illustrated in Figure 5-18. Once the rehabilitation process is initiated, the flows are step functions of time as the rehabilitated site changes from stage 1 in the first year to stage 2 in the second year to stage 3 in all following years. Similarly, the decision to cut or not to cut is a step function. The flows of land related to deforestation and rehabilitation are an increasing linear function of the acreage in the land to be transferred at a given time.

5.5.10 Terrestrial Plant Translocation and Shattering

At the level of detail provided in the present conceptual model, translocation up or translocation down of carbon within the plant system is controlled as a sinusoidal function of time (Figure 5-19). Transpiration is visualized as a proportional flow and thus is also a direct linear function of the amount of root and shoot biomass.

70	EVAPORATION, FROZEN
71	EVAPORATION, WATER
73	STREAMFLOW
76	SURFACE WATER RUNIN
77	SURFACE WATER RUNOUT
78	LITTER FLOW IN
79	LITTER FLOW OUT

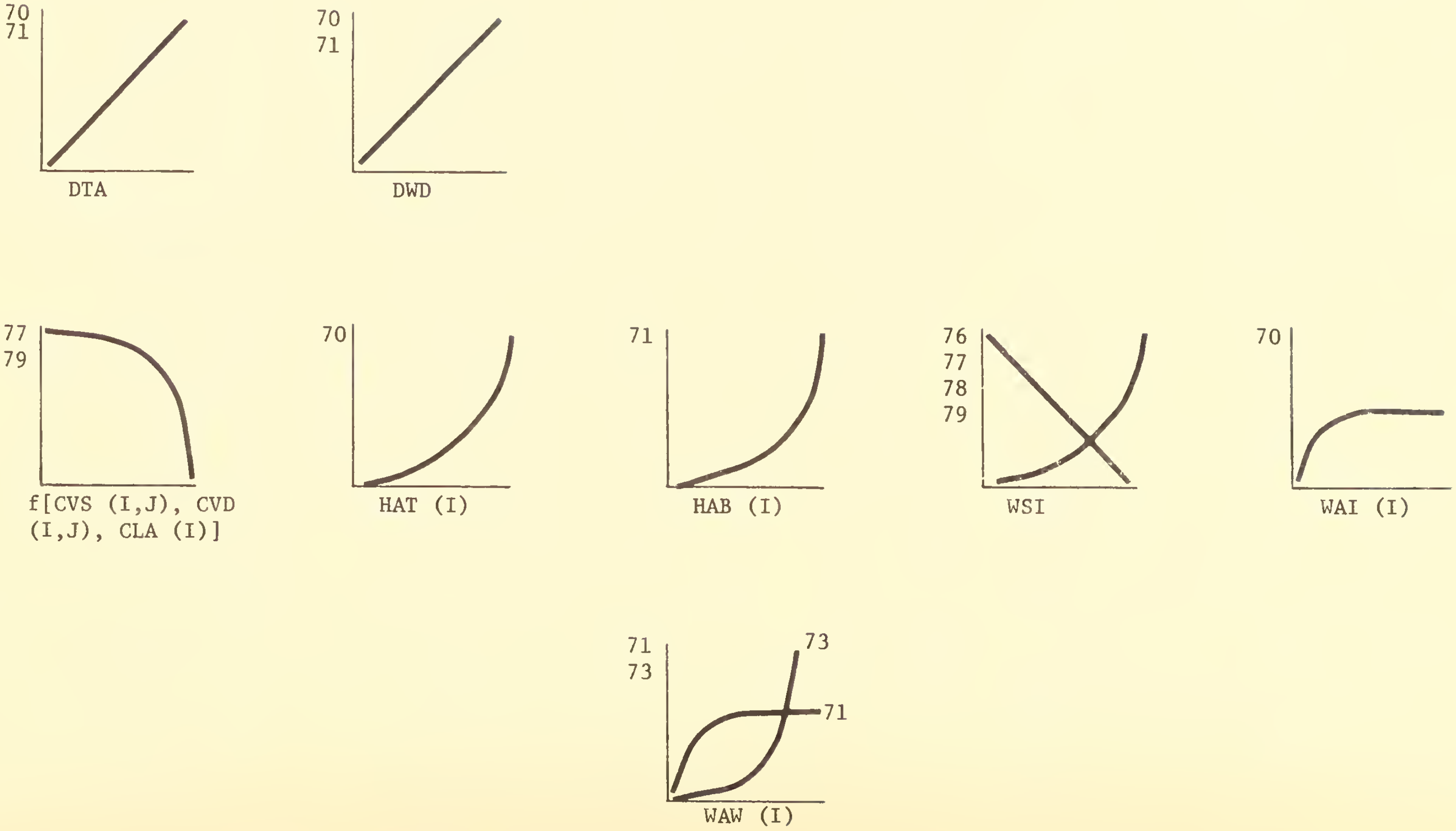


Figure 5-16 EVAPORATION, STREAMFLOW, SURFACE WATER TRANSFERS, AND LITTER FLOW TRANSFERS (PROCESSES 70, 71, 73, 76, 77, 78, and 79).

37	TRANSPIRATION, TOPSOIL
39	TRANSPIRATION, BOTTOM SOIL
72	TRANSPIRATION, AQUATIC
80	GROUND WATER IN
81	GROUND WATER OUT

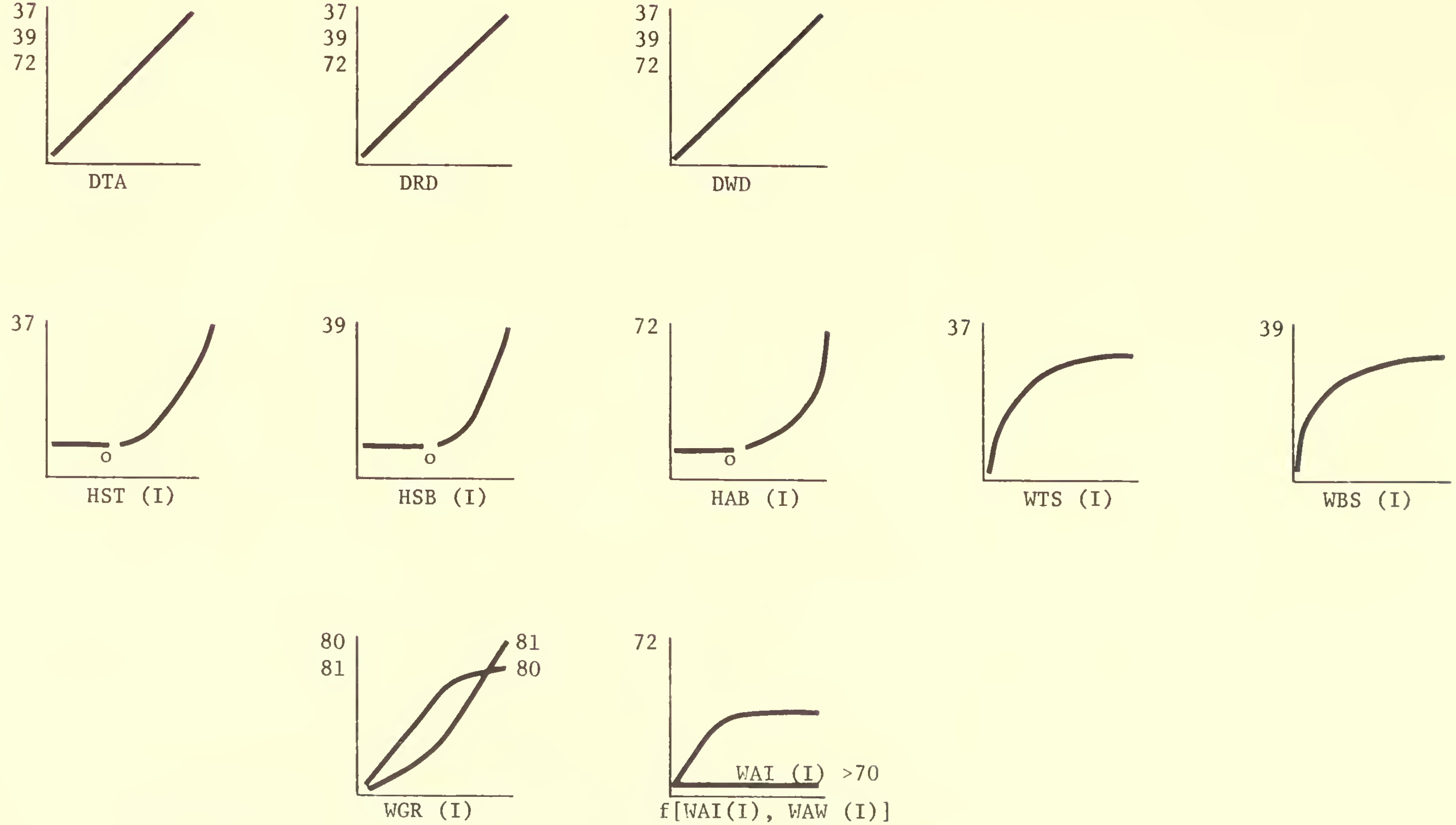
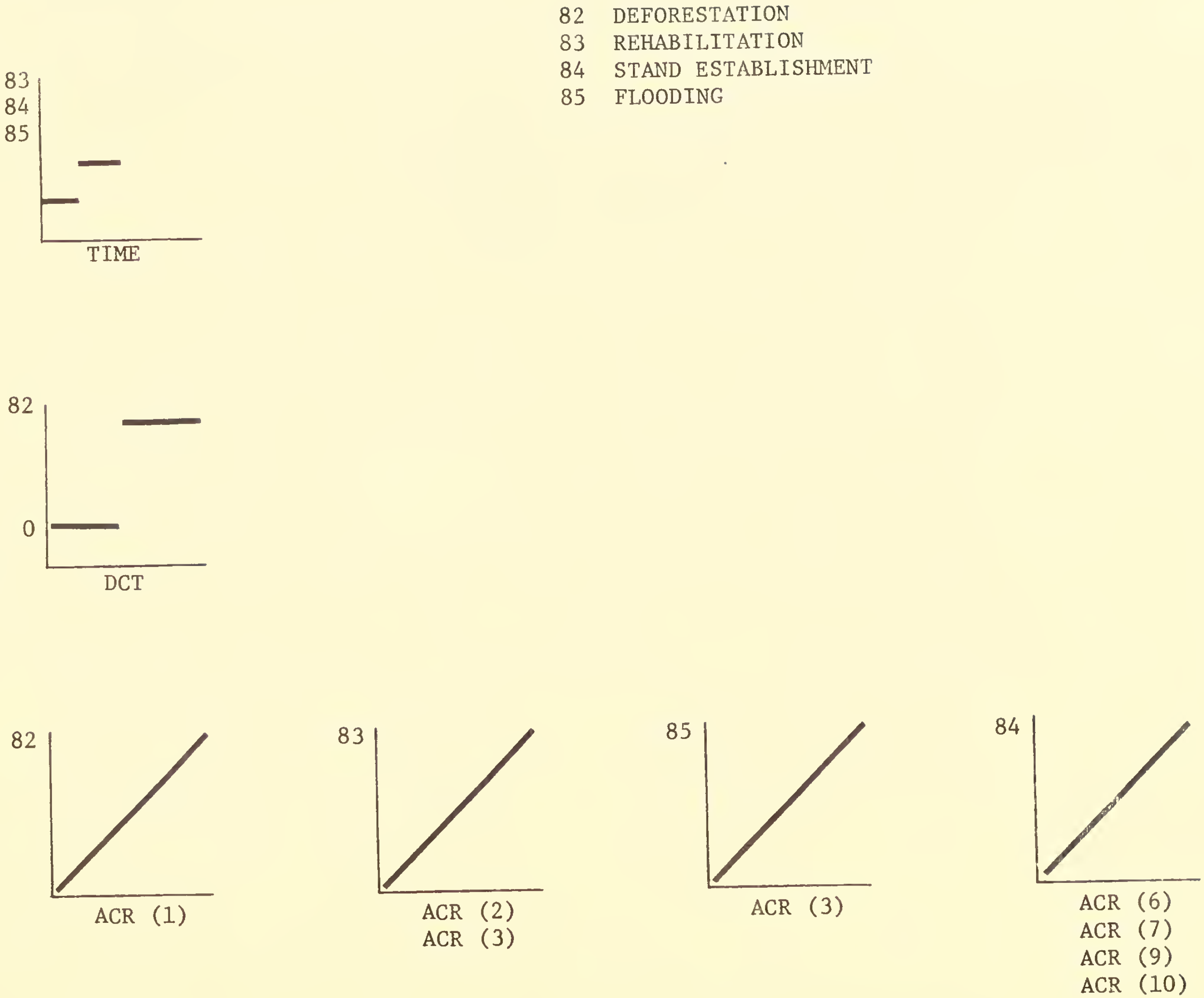


Figure 5-17 FACTORS AFFECTING TRANSPIRATION FLOWS IN THE AQUATIC SYSTEM AND GROUNDWATER FLOWS (PROCESSES 37, 39, 72, 80, and 81).



82 DEFORESTATION
83 REHABILITATION
84 STAND ESTABLISHMENT
85 FLOODING

Figure 5-18 FACTORS AFFECTING FLOWS OF LAND AREAS (PROCESSES 82, 83, 84, and 85).

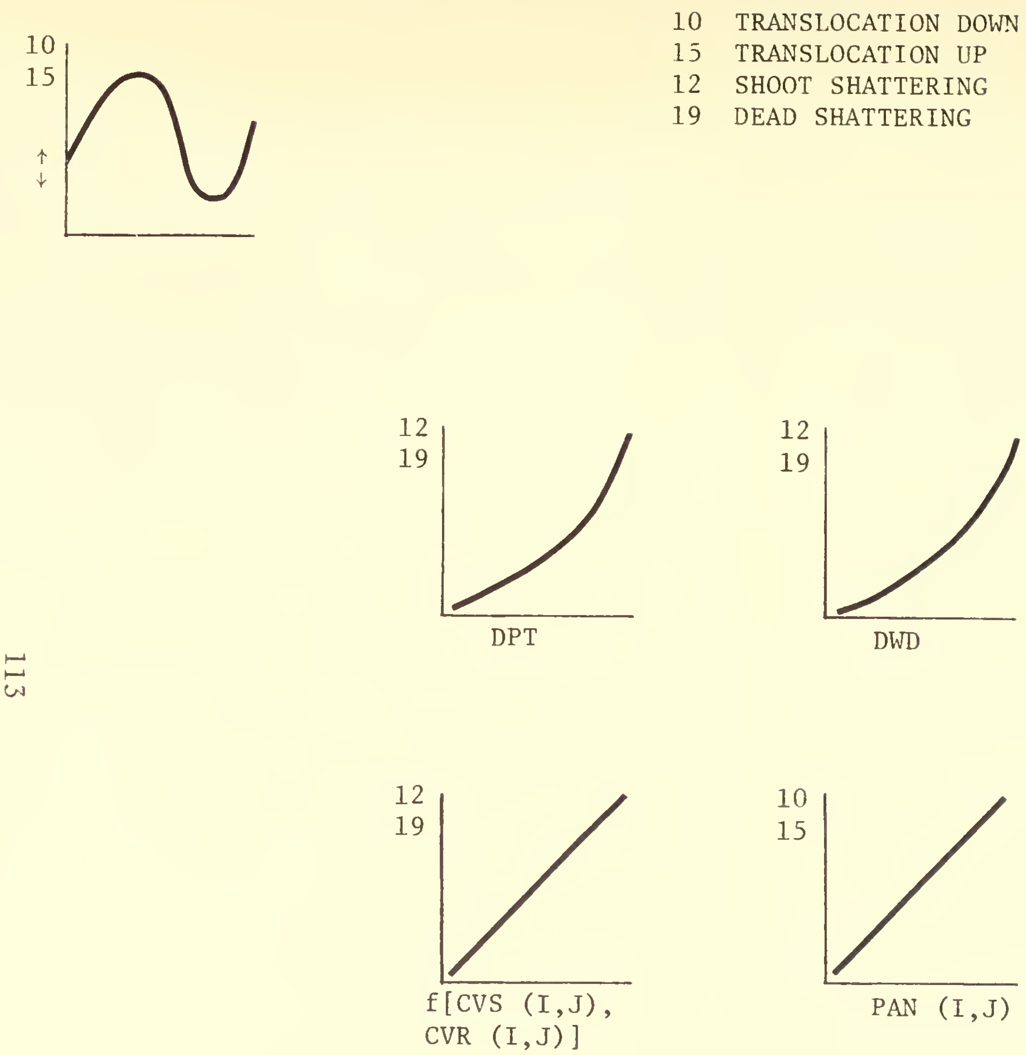


Figure 5-19 FACTORS AFFECTING TRANSLOCATION FLOWS AND SHATTERING OF LIVE AND DEAD SHOOTS IN TERRESTRIAL PLANTS (PROCESSES 10, 12, 15, and 19).

Shattering of live and standing dead shoots is a linearly increasing function of animal population density PTA(I,J) and an exponentially increasing function of precipitation and wind.

5.5.11 Natality, Mortality, and Dead Animal Input

Natality and mortality in the terrestrial system are a function of time (Figure 5-20). Some animals reproduce twice during the year, such as deer mice and voles. They represent multilitter animals. For example, the number of young produced per hectare may approach 20 in late May and early June and again in late July and early August. Other animals produce only a single litter such as the chipmunks, ground squirrels, and wood rats. The number of young produced here may approach 12 per hectare in late April and early May.

Several driving variables including temperature and oil shale development-related variables (e.g., trace metal contaminants, carbon monoxide emission, noise and activity disturbance, and hunting and recreation) can influence mortality and natality rates (Figure 5-20). Mortality and dead animal input flows are concave curvilinear flows with a minimum at an optimal temperature for the organism. In contrast, natality flows are concave curvilinear flows with a maximum at a particular temperature suited to the given organism. Natality in the terrestrial and the aquatic system is assumed to be a linearly decreasing function of Tract metal contaminants. Mortality in the terrestrial and aquatic system is a linearly increasing function of trace metal contaminants. Natality is a linearly decreasing function in the terrestrial system of DOL(5), DOL(8), and DOL(9). The reverse is true for mortality.

Mortality is linearly and inversely related to food availability for the particular organisms involved.

Mortality and natality are density-dependent relationships for aquatic vertebrate and invertebrate animals and terrestrial animals. Mortality is a linearly increasing function of animal population size, as is dead animal input into the aquatic or terrestrial systems. Natality is either an exponentially decreasing function or a logarithmically decreasing function of population size. Limited data show that the number of young of many of the small mammals has a logarithmically decreasing functional relation to the population size. When population size goes from 20 up to 50 animals per hectare the number of young produced drops from 11 down to about 3 per hectare.

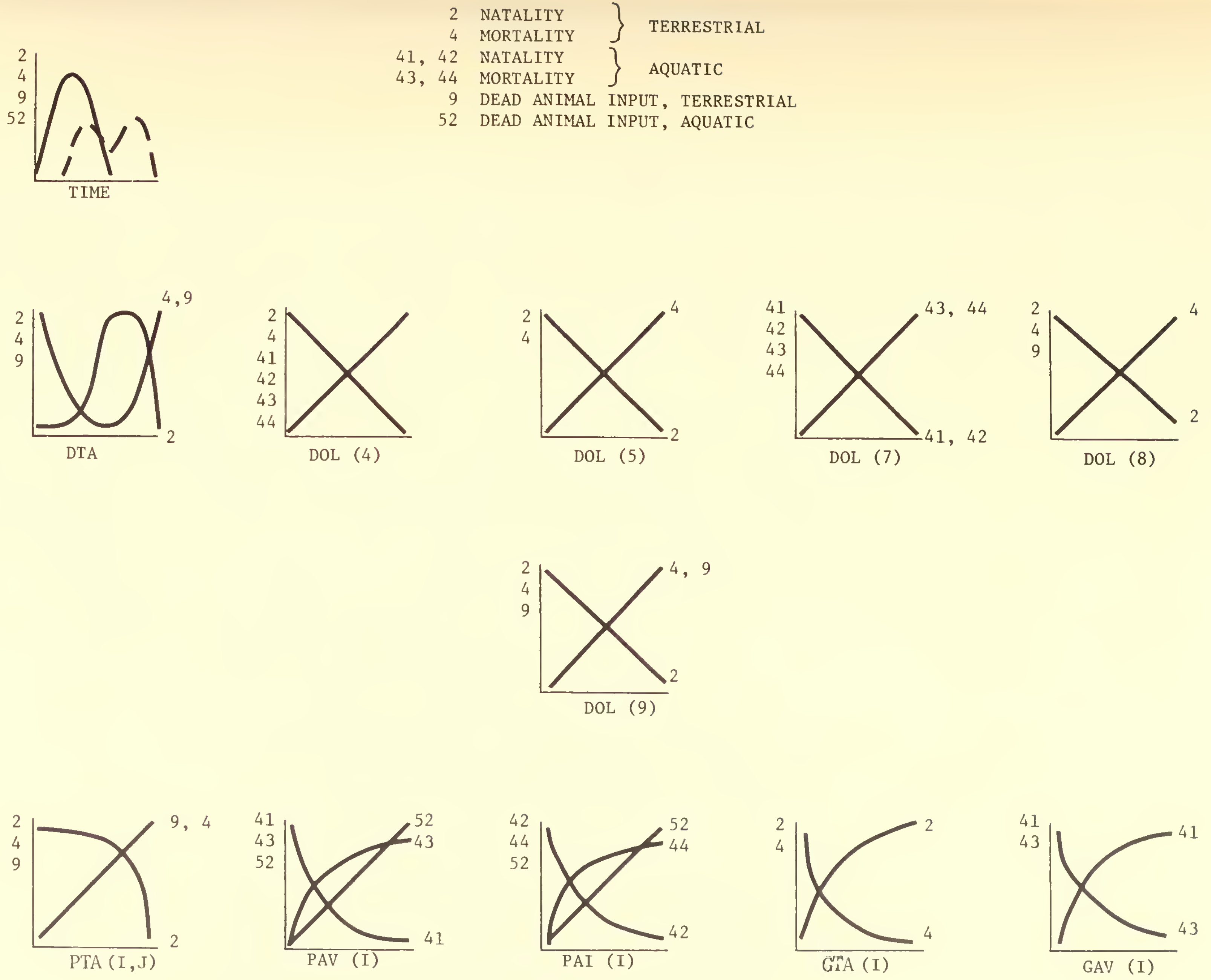


Figure 5-20 FACTORS AFFECTING NATALITY, MORTALITY, AND DEAD ANIMAL INPUTS INTO TERRESTRIAL AND AQUATIC SYSTEMS (PROCESSES 2, 4, 9, 41, 42, 43, 44, and 52).

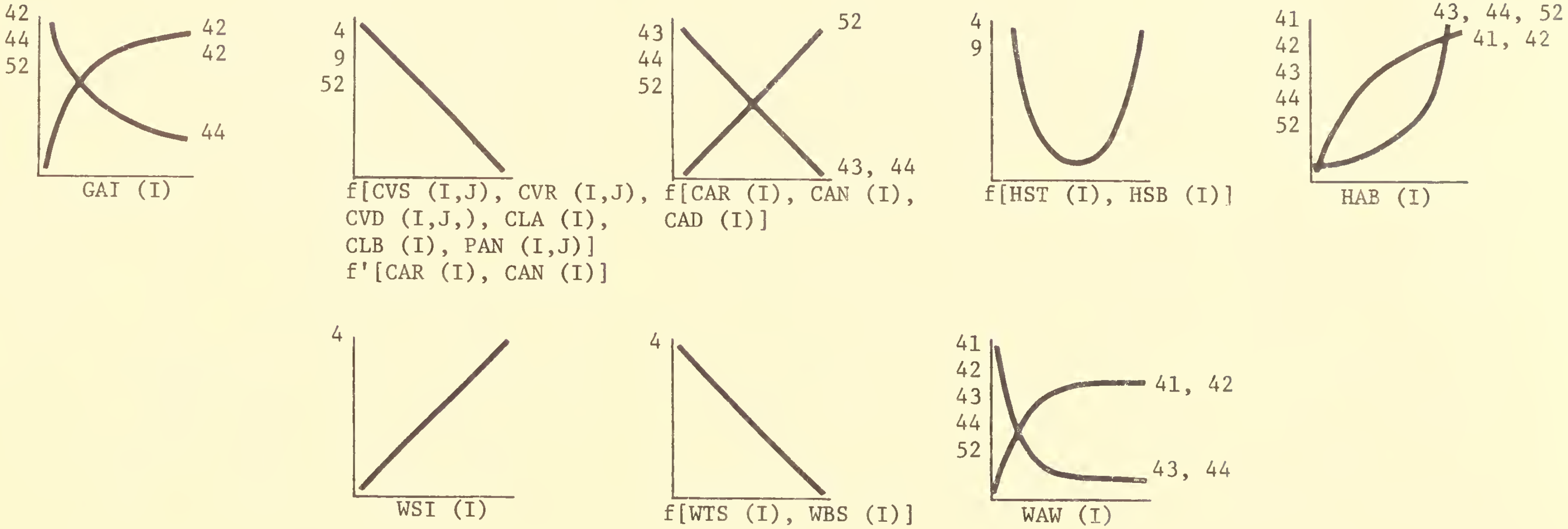


Figure 5-20 FACTORS AFFECTING NATALITY, MORTALITY, AND DEAD ANIMAL INPUTS INTO TERRESTRIAL AND AQUATIC SYSTEMS (PROCESSES 2, 4, 0, 41, 42, 43, 44, and 52). (CONTINUED)

In some conceptual models it is necessary to keep account of the age of individual organisms. As the animals grow older there is an exponentially increasing relationship of mortality to age. However, separate age cohorts are not accounted for in the present conceptualization.

Soil temperature or water temperature both influence organisms living in those habitats. These and other relationships affecting mortality and natality are shown in Figure 5-20.

5.6 Flow Control Diagrams

For cause-and-effect reasoning about how various factors influence the system,it is necessary to have more than the general system flow diagram (Figure 5-6) and an effects matrix (Figure 5-7). One also needs to keep in mind the dynamics of the driving variables and the state variables under naturally occurring conditions (Figures 2-1 through 2-9). Each of the driving variables and state variables affects a given flow in different ways (Figures 5-8 through 5-20). When one is dealing with a real-life, complex problem (such as oil shale development) the system is so complex that it is difficult to place all the information into a single picture. It is even more difficult to incorporate enough of the information in one glance to use in cause-and-effect reasoning. The overall system flow diagram (Figure 5-6) is an aid in the reasoning process, but it needs to be supplemented with diagrams that focus on individual flows and the factors immediately around them. This is the purpose of a "flow-control diagram" an example of which is given in Figure 5-21.

A flow-control diagram is useful in focusing on how an individual flow will vary over time. It shows adjacent to it the compartment from which the flow originated and the compartment to which the flow is destined. In the example in Figure 5-21 the focus is on the death of live shoots. The carbon that flows through the death process must come from the live shoot compartment and end in the standing dead compartment. The time-series dynamics of these compartments is shown in the rectangles labeled as live shoots and standing dead. Several factors, e.g., temperature and wind, affect the death process. Therefore it is necessary to show the functional relationship between temperature and death and between wind and death. In this case death of live shoots is viewed as an increasing exponential function of both temperature and wind. It is also important to show the dynamics of wind and temperature as driving variables. Thus the time-series graphs for these variables are entered into the appropriate pentagons in the diagram.

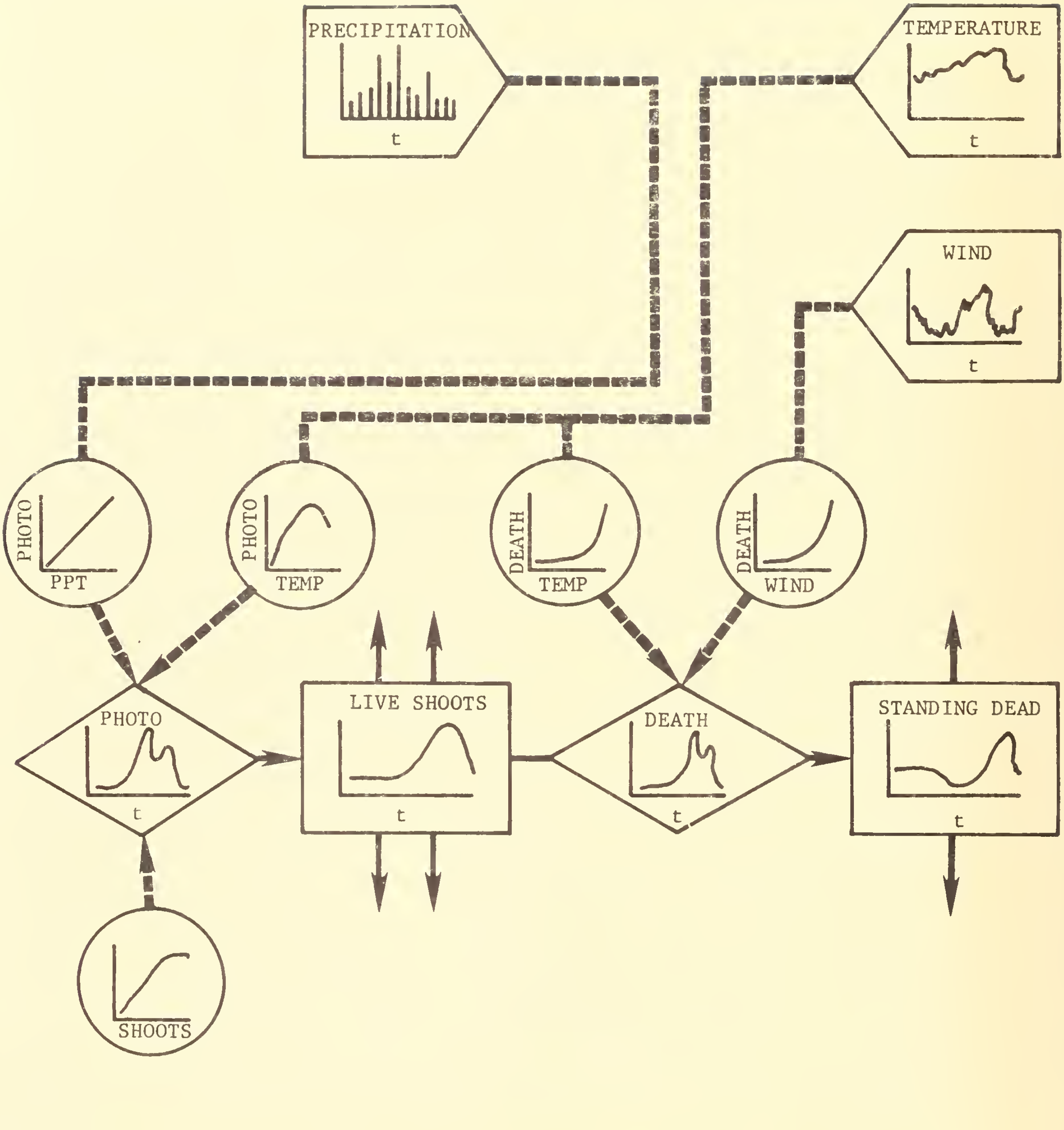


Figure 5-21 AN EXAMPLE STRUCTURE FOR A SEGMENT OF A CAUSE-AND-EFFECT SYSTEM FRAMEWORK

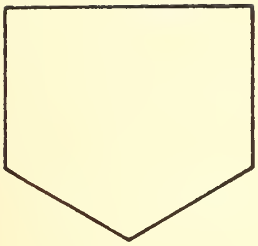
The flow control diagrams, then, focus on a single flow at a time and show the time dynamics of the associated variables and the functional relationships to those variables using these diagrams and an overall system flow diagram (Figure 5-6) to show the place of the individual flow in the larger picture, it is possible to reason how a change in a driving variable or state variable could influence a flow and thus could influence the variables in the system. This reasoning reinforces the adage of ecology that "everything affects everything else." The adage is true, but the effects are sometimes of second, third, fourth, or higher order or linkage.

Figure 5-22 presents 85 types of flows in a flowcontrol diagram format. Symbols are explained in Figure 5-23. This figure brings together particular segments out of the total system flow diagram (Figure 5-6) showing the location of the flow between two state variables. It illustrates the dynamics of the driving variables and the state variables affecting a given flow as derived from Figures 2-1 through 2-9. It shows the functional relationship of how each driving variable and each state variable influences the particular flow as derived from Figures 5-8 through 5-20. When used in concert with the overall system flow diagram (Figure 5-6) the flow-control diagrams are a powerful tool to assist reasoning about expected changes in the system due to manipulation of driving or state variables. One problem remains, however, that of how to combine all the factors affecting single flow into one mental or numerical equation.

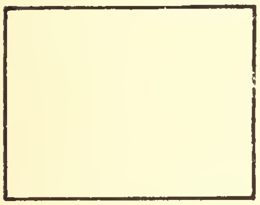
Inspection of the effects matrix (Figure 5-7) or the relational diagrams of how factors affect flows (Figures 5-8 through 5-20), or the flow-control diagrams (Figure 5-22) clearly indicates that multiple factors influence the flows in our conceptualization of how the Tract C-b system operates. To utilize a mental or numerical approach that has a single-factor focus would be erroneous. Similarly, to assume that the flow is constant through time would be erroneous. Furthermore, to assume that the flow is simply a constant proportion of a donor or receiver compartment would be overly simplistic. If we rule out these three approaches to calculating flows, we rule out the use of simplified modeling approaches for either dealing with mental models or numerical models. Thus, for example, we could not use first-order, constant-coefficient, linear differential equations systems to represent the dynamics of the variables on Tract C-b. It simply would be over-simplistic and naive. It would not allow us to incorporate much of the knowledge we have used in structuring our present model, as simplistic as it is. It would not allow us to relate parameters or coefficients in functional relationships to real-life measurable properties.

Figure 5-22 FLOW-CONTROL DIAGRAMS FOR 85 PROCESSES IN THE TRACT C-b ENVIRONMENTAL SYSTEM. LEGEND IS PRESENTED IN FIGURE 5-23.

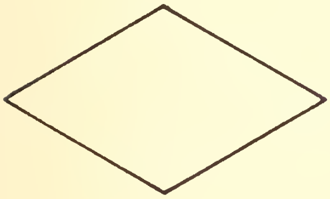
(Refer to Supplementary Envelope)



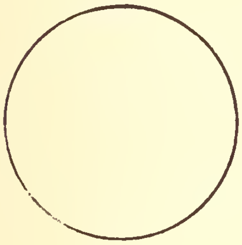
Driving Variable. Graph describes the "normal" behavior of the particular variable over time.



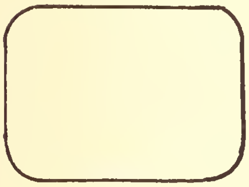
State Variable. Graph describes the "normal" behavior of the particular variable over time.



Rate of Flow between origin and destination. This is the sum of the influences on the specific process.



Influence of a given variable on the process. Ordinates are unnumbered here because the exact numerical relationship is unknown, although the general form of the curve is established.



Rate of Process as it was measured or estimated under "normal" conditions.

Figure 5-23 SYMBOLS AND THEIR MEANINGS FOR FIGURE 5-22

Implementation of the conceptual model developed in this chapter into a quantified, computer-based model capable of projecting the complex ramifications of the assumptions set forth here is beyond the scope of this project. At the present time sufficient data are available to start a numerical prediction model, and some ideas for how this can be done are contained in Appendix E, "Suggestions For Building A Mathematical Model to Similate Environmental System Dynamics on Tract C-b."

It suffices here, however, to utilize the system flow diagram (Figure 5-6) and the flow control diagrams (Figure 5-22) with reasoned judgement and background experience to make projections as to what the flows might be and how various factors manipulable by man in oil shale development might influence these flows. The main thing we have done at this stage is to develop a conceptual framework and relate it to the baseline data. The time-series information in the rectangles of Figure 5-22 are taken directly from Figures 2-1 through 2-9. The framework was prepared in the context of its potential future utility for incorporating oil shale development influences. The conceptual framework put forward potentially can be implemented numerically. It can be utilized "as is" in qualitative cause-and-effect reasoning about how the system operates and how various factors influence this operaton. If it is numerically implemented, it could be utilized quantitatively in making predictions of how the system would change under various situations and conditions.

5.7 Summary

This chapter synthesizes the materials developed in Chapters 2, 3, and 4 into a holistic conceptual model of the Tract C-b environmental system. It ties the natural system state and driving variables discussed in Chapter 2 with the oil shale development influences discussed in Chapter 4. These variables are then linked together conceptually with the processes discussed in Chapter 4 by means of a master effects matrix (Figure 5-7), a total system flow diagram (Figure 5-6), and a set of flow-control diagrams (Figure 5-22).

6 AN APPROACH TO ANALYZING MAJOR INTERRELATIONSHIPS ON TRACT C-b

6.1 Introduction

Thus far, Volume V has analyzed the Tract C-b environmental system by identifying important system components and processes. It then synthesized the information by demonstrating how these components are linked by flows of various kinds of currencies through the environmental system, flows that are controlled by the processes. Chapter 6 carries the synthesis one step further by developing total system diagrams that contain the controls and feedback loops as well as the flows.

Within every terrestrial ecosystem response unit are five subsystems, each conceived around a particular flow currency. The aquatic response unit likewise contains five flow currency subsystems. The linkages within each subsystem are the currencies: carbon, heat, water, animal numbers, and animal weights. Linkages between the subsystems are flows of information, water, and mobile animals. Effectively, the information linkages can be viewed as conversion factors: e.g., a particular number of animals will have a given effect on carbon flow by decreasing the plants; or, conversely, as plant biomass (carbon) increases, animal biomass (kilograms) might increase also. The relationship between the two can be defined mathematically, although the explicit mathematical definitions among processes and components are beyond the scope of this volume. This is what is meant by information flow between subsystems, however.

Information flows are classified into three types for ease of identification. The first type is the flow linking state variables from one subsystem to a process in another subsystem. A second type links the state variables in a particular subsystem to the process within that same subsystem. This type is known as a "feedback" loop, or cybernetic linkage. A third type of information linkage originates at the driving variables and provides input to those processes influenced by driving variables.

Chapter 6 attempts to show how the components and processes are linked by both material flows and information flows. Terrestrial and aquatic system diagrams are used to illustrate these linkages.

6.2 Symbols and Conventions

To make the diagrams as easy as possible to follow, certain symbols and conventions have been used uniformly throughout (Figure 6-1). Sources or sinks are conceptually outside the system; they can donate or receive an infinite amount of the flow. A complete list of system components and processes, along with their acronyms and other information about them, is found in the User's Reference (Appendix F).

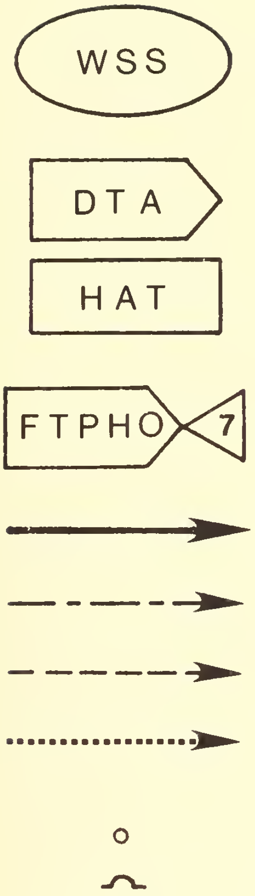
6.3 The Aquatic System

Although considered an ecosystem response unit, the aquatic system (Figure 6.2) differs sufficiently from the terrestrial ecosystem response units to warrant special attention as one of the two broad categories of environmental systems (aquatic and terrestrial) within Tract C-b. The five flow currency subsystems are the same as those of the terrestrial system.

In the animal population subsystem the aquatic animals are aggregated into two broad categories: vertebrates (PAV) and invertebrates (PAI). The population dynamics are controlled conceptually only by the processes of birth and mortality. Implicit within those two broad processes are processes such as courtship behavior for higher vertebrates, and mortality due to a variety of causes (e.g., predation, starvation, pollution). Growth and respiration are the processes that control dynamics of the animal weight subsystem, composed of aquatic vertebrates and invertebrates (GAV and GAI). These two systems are linked via information flows. For example, the vertebrate population (PAV) influences the growth and respiration of the vertebrate animal biomass (GAV), and the animal biomass in turn influences birth and mortality of animal numbers.

The carbon biomass subsystem contains three state variables in the aquatic system: rooted plants (CAR), nonrooted plants (CAN), and detritus (CAD). The processes operating in this subsystem are photosynthesis, excretion input, dead animal and plant inputs, respiration, grazing, and decomposition. These processes are all controlled by information linkages both within the subsystem and outside. There are influences from each of the other four subsystems acting on the carbon subsystem.

There are two heat state variables in the aquatic subsystem: top layer (HAT) and bottom layer (HAB). The flow of heat within this system is controlled mainly by the driving variables temperature (DTA), wind (DWD), and solar radiation (DRD). However, the heat dynamics affect processes in all the other subsystems, as shown by the information linkages emanating from this subsystem (Figure 6-2).



Source or sink. The initial letter identifies the particular subsystem: W = water; H = heat; C = carbon; P = animal population; and G = animal weight.

Driving variable. The initial D identifies all driving variables.

State variable. The initials follow the same conventions as sources and sinks.

Process. These may be thought of as valves that control the flows of matter or energy through the subsystem. The initial F of the acronym identifies a process, and the number specifies which process.

Material or energy flow. Denoted by a solid line.

Information flows. Dots and dashes represent input from driving variables. Dashes trace the inter-subsystem influences of state variables on processes. Dots are the intra-subsystem feedback loops through which state variables influence processes within their own subsystems.

Takeoff points and crossings. The small circles represent take-off points or branches in information linkages. The other symbol simply denotes a crossover.

Figure 6-1 SYMBOLS AND CONVENTIONS USED IN THE SYSTEM DIAGRAMS

Figure 6-2 GENERAL AQUATIC SYSTEM DIAGRAM FOR TRACT C-b

(Refer to Supplementary Envelope)

The two water state variables are actually water in two different states: solid ice (WAI) and liquid (WAW). The processes in this subsystem are driven by the driving variables precipitation (DPT), temperature (DTA), wind (DWD), and solar radiation (DRD), and the heat state variables, HAT and HAB. The amount of water, WAW, however, affects many of the biotic processes throughout the system, as might be expected.

From Figure 6-2, major interactions in the aquatic system can be identified, and the far-reaching effects of disturbances at one part of the system on other parts can be traced. A method for doing this is described in Section 6.5.

6.4 The Terrestrial System

There are four existing terrestrial ecosystem response units on the Tract C-b site and two potential such units after oil shale development operations begin (Table 2-3). Although specific soils, topography, life forms, and species may differ between ecosystem response units, the conceptual structure of the terrestrial system is general enough to be applied to all response units. Figure 6-3 presents a system diagram for a generalized terrestrial ecosystem response unit on Tract C-b. As in the aquatic system, the flow currencies are carbon, animal numbers, animal weights, heat, and water.

The terrestrial animal population subsystem is controlled conceptually by four processes: natality, mortality, immigration, and emigration. All animals, vertebrates and invertebrates, are included in the state variable PTA. However, for expanding this particular subsystem, there are potentially 10 categories of animals available (Table 2-4), ranging from cattle to arthropods. Many more detailed subprocesses are implicit in the four major processes listed, but for the conceptualization at this level of resolution, only the four broad processes were included. Patterns of immigration and emigration are influenced mainly by driving variables (temperature and grazing regulation as well as noise, activity, recreation, and hunting attributable to oil shale development) and water. Many of these same variables also affect mortality and natality of populations.

The subsystem of terrestrial animal biomass is controlled by different variables than those controlling the animal populations. Many of the plant carbon state variables influence animal growth as food availability fluctuates. Temperature and three development driving variables affect animal respiration. Soil temperature and soil water also affect animal growth.

The hydrological subsystem is influenced by the four natural driving variables, temperature, precipitation, wind, and solar

Figure 6-3 GENERAL TERRESTRIAL SYSTEM DIAGRAM FOR TRACT C-b

(Refer to Supplementary Envelope)

radiation. There is also quite a bit of input from the plant subsystem in the form of influences on several hydrological processes. For instance, live roots (CVR) and belowground litter (CLB) affect infiltration, and live shoots (CVS), aboveground litter (CLA), and standing dead (CVD) all influence evaporation from the topsoil. Other influences come from the soil temperature.

Heat flows through the system are affected by driving variables (temperature, wind, and solar radiation) and soil water.

The most complex of the 10 subsystems diagramed in this chapter is the terrestrial carbon flow subsystem. With 18 processes controlling flows among five state variables, a source, and a sink, this subsystem is perhaps the most important on Tract C-b. Because vegetation is an integrator of many ecosystem components (soil types, topography, climatological factors, animal behavior, etc.), and because it often provides early warning of changes in the environmental system, it logically deserves the most attention. The state variables divide the vegetation into three plant parts, live shoots (CVS), live roots (CVR), and standing dead (CVD). The conceptual model further permits the expansion of these state variables into five life forms (Table 2-4) if necessary for a more detailed look at carbon flow. The two other state variables in this subsystem are aboveground (CLA) and belowground (CLB) litter. The list of processes that control carbon flow among these state variables is too large to discuss in detail here; it can be seen in Figure 6-3. Because vegetation is such an important part of the C-b environmental system, many other parts of the system influence carbon flow and are, in turn, influenced by vegetation dynamics.

6.5 Analyzing System Interrelationships: Cause-Effect Reasoning

Figures 6-2 and 6-3 were designed to be used on a wall or large table for tracing interactions and influences throughout the system. The effects matrix (Figure 5-7) also should be used as a separate oversize foldout. These three figures, in conjunction with the flow control diagrams (Figure 2-22), the simplified dynamics of the ecosystem components (Figures 2-1 through 2-9), the diagrams of factors affecting environmental system processes (Figures 5-8 through 5-20), and the time-series graphs (Figure B-1), can be used to study the interactions of variables within the environmental system and thereby anticipate needs for mitigation and monitoring on Tract C-b.

There are several ways of approaching cause-effect reasoning using the matrix and other figures mentioned above. For example, consider all the possible influences exerted by noise and activity, the oil shale development driving variable called DOL(8). Figure 5-7 shows that seven animal biotic processes and one biotic component would probably be affected in some way by noise and activity.

Furthermore, the matrix suggests that seven of these effect receptors would be affected directly and one, indirectly. Three of these effects are of particular concern: animal reproduction, animal movement, and general habitat disturbance. Reproduction as defined in the glossary includes factors associated with courtship, mating, and nesting or calving. It is implicit in the process of animal natality in the conceptual model. Animal movement includes four processes defined in the conceptual model: terrestrial animal immigration, emigration, transfer in, and transfer out. General habitat includes a broad spectrum of different vegetative types that provide cover, food, resting place, etc., for animals on the Tract C-b.

Having identified important components and processes affected by DOL(8), the user can turn first to Figure 5-20 to determine that there is a positive linear relationship between increased noise and activity and terrestrial animal mortality, and a negative linear relationship between DOL(8) and natality. Similar relationships exist between DOL(8) and animal movement (Figure 5-8), resulting in a net decrease of animal numbers as noise and activity increase.

The next question is: How far-reaching are these effects throughout the system? Figure 6-3 permits the user to trace the ramifications of these effects from the animal subsystem to other subsystems. Decreased terrestrial animal populations, of course, will result in decreased overall animal biomass on the Tract. But Figure 6-3 shows that DOL(8) will affect animal growth and respiratory processes, and Figure 5-9 depicts that relationship. The result is net decrease in animal biomass independent of that postulated from examining the population subsystem. This suggests a mutually reinforcing interaction, a negative synergism, that will further depress the animal numbers and biomass on the site, if DOL(8) increases sufficiently.

The animals, acting through state variables PTA and GTA, interact strongly with the vegetation (Figure 6-3). For example, the population (PTA) influences excretion input, dead plant shattering, live shoot shattering, shoot grazing, belowground litter grazing, dead animal input, root grazing, dead plant grazing, and aboveground litter grazing. How these processes are affected is depicted in the series of Figures 5-8 through 5-20. Such an analysis begins to demonstrate specifically the close interrelationships between the animal and plant subsystems.

At any point in the above analysis, a user could have chosen to examine a particular process in more detail, possibly trying to determine what else influences that process. For example, what besides noise and activity affects the process of population mortality (FTMOR)? Figure 5-22 provides a somewhat detailed answer: Terrestrial animal mortality is affected by the driving variables of temperature, trace metal contaminants, carbon monoxide emissions, noise and activity disturbance, and secondary hunting and recreation. State variables affecting this process are live shoots, live roots, standing dead, aboveground litter, belowground litter, soil temperature, soil water, surface water, animal biomass, and animal numbers. The types of relationships that exist between all these variables and the process of terrestrial mortality are graphically displayed in Figure 5-22-4.

In this particular figure it is possible to see at a glance the behavior of a given state variable over time, as measured, recorded, and summarized from the baseline study. The rectangles represent this time-series summary. The circles present the relationship between the variables and the process. For example, the driving variable of temperature increases and decreases seasonally, as might be expected. The effect of temperature changes on terrestrial animal mortality is shown in the upper left-hand circle containing the parabola (Figure 5-22-4). This relationship says simply that extremes of temperature have a large effect on mortality, while moderate temperatures have little effect.

This cause-effect reasoning can be carried out for changes in several individual driving variables, alone or in combination. The reality of the situation now becomes very clear. One can look at the influence of several man-controlled driving variables on a large number of flows in the conceptual system model. The response of the flows to changes in these man-controlled, development-related driving variables depends upon, and interacts with, the nature-controlled driving variables. A user thus must look at many variables simultaneously and under many conditions. This results in a staggering number of combinations. The problem suggests the need for a numerically implemented simulation model of the structure and function of the Tract C-b system. Then, in addition to providing a framework in which to synthesize information about system components, it would be possible to generate overall system behavior for different hypothesized situations representing combinations of man-controlled driving variables and nature-controlled driving variables. The output of such a massive amount of numerical computation is weighty, but having the information in a machine-readable format allows rapid reduction and analysis. Suggestions for implementing such a model is discussed in Appendix E.

6.6 Summary

Two total system diagrams are developed and presented in this chapter, one for the generalized terrestrial system and one for the aquatic system. The user is directed how to use these diagrams in conjunction with figures developed earlier in this volume to infer cause-effect relationships throughout the Tract C-b environmental system.

7 MAJOR ECOLOGICAL INTERRELATIONSHIPS

7.1 Introduction

From an almost infinite number of interrelationships that exist among components and processes in the Tract C-b environmental system, this chapter identifies and discusses major relationships that are relatable to oil shale development, either directly or indirectly. Using the conceptual model developed in preceding chapters, this chapter describes how some of the potential effects due to oil shale development might be felt throughout the system far beyond the initial point of entry. How these potential effects will be handled is the scope of the monitoring and mitigation programs.

During the planning of this volume, three criteria were selected to identify key ecological interrelationships: (1) relatability to oil shale development, (2) observability, and (3) measurability. The first criterion is applied in this chapter; application of the other two to monitoring and mitigation is discussed in Chapter 8.

Although the criterion "relatability to oil shale development" is applied here, it should be stressed that the development plans call for careful mitigation of potential environmental disturbances. Types and quantities of anticipated pollutants have been projected, and every precaution has been taken to control them. Nonetheless, the oil shale development activities constitute sources of potential impacts, and these are the interrelationships addressed here. In the event of human or equipment failure, these are some of the things that could be affected. The list in Table 7-1 comprises effects identified as of particular concern in Figure 5-7, the effects matrix.

7.2 Abiotic-Abiotic Interrelationships

Interrelationships among abiotic components and processes in the Tract C-b environmental system are important primarily because the abiotic portion of the system usually functions as a medium for transporting environmental perturbations between the source and the biota of the system. The most important media, of course, are air and water. Any types of solid, liquid, or gaseous perturbation from man's activities generally travels through the air or water to living components of the system. Exceptions are discharges directly onto the soil, destruction of wildlife habitat, and other drastic, direct effects that are obvious. The effects of perturbations on the transport media are discussed in this section.

Table 7-1

EFFECT GENERATORS ANTICIPATED FROM OIL SHALE DEVELOPMENT AND THEIR RECEPTORS

Effect Generator	Effect Receptor
Sulfur emissions - DOL(1)	Terrestrial plant growth - FTTRS, FTTRR, FTTRU, FTTRL Litter decomposition FTABD, FTBED
Oxidants - DOL (3)	Terrestrial plant growth - FTTRS, FTTRR, FTTRU, FTTRL
Fluoride emissions	Terrestrial plant growth - FTTRS, FTTRR, FTTRU, FTTRL Terrestrial animal growth - FTGRO Animal tissue*
Trace elements - DOL(4)	Terrestrial plant growth - FTTRS, FTTRR, FTTRU, FTTRL Terrestrial animal growth - FTGRO
Noise and activity - DOL(8)	Terrestrial animal reproduction* Terrestrial animal movement - FTIMM, FTEMI, FITRI, FITRO General habitat
Disturbed vegetation	General habitat
Unrevegetated bare areas	Runoff - FIWRI, FIWRO General habitat
Transmission lines and pipelines	General habitat
Erosion	Runoff - FIWRI, FIWRO Streamflow - FASTR
Mixed soil profile	Revegetation - FIRHB, FISTD
Altered soil chemistry	Terrestrial plant growth - FTTRS, FTTRR, FTTRU, FTTRL Revegetation - FIRHB, FISTD
Sedimentation	Aquatic plant growth - FATRW Aquatic vertebrate growth - FAGRV Aquatic invertebrate growth - FAGRI

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*Defined in glossary.

Table 7-1

(Continued)

EFFECT GENERATOR	EFFECT RECEPTOR
Altered surface water	Aquatic plant growth - FATRW Aquatic vertebrate growth - FAGRV Aquatic invertebrate growth - FAGRI
Water table alterations	Streamflow - FASTR Water quality

7.2.1 Air As A Transport Medium

Of the many different types of environmental perturbations identified in Figure 5-7, five have potentially significant impact on the environmental system: sulfur emissions, oxidants, fluoride emissions, trace elements and noise and activity. Of these five, fluoride emissions was the only one not addressed in the detailed development plan, but it is included because several principal investigators during the baseline study mentioned the possibility of fluorides being released in the atmosphere from the various mining processes, either from the shale processing itself, or from the dewatering water from the mine. In view of the careful mitigation plans proposed by the oil shale development team, it is unlikely that emissions will have any wide ranging or long-term climatic effect on or near the Tract C-b. However, these emissions might have an effect on several biotic processes, and these are discussed in Section 7.3.

7.2.2 Water As A Transport Medium

Four possible major impacts involving water as a transport medium are listed in Table 7-1: erosion, sedimentation, altered surface water flows, and water table alterations. Erosion will affect surface runoff and streamflow. The sedimentation and altered surface water flows connected with erosion will have some effects on the aquatic biota, as described in the next section. Water table alterations will affect streamflow and water quality in general. Specifically, a lowered water table associated with deep mining activities would reduce the alluvial groundwater flow that feeds the streams. In addition, as the water table was lowered, the quality of water available to the surface would decrease, as suggested by tests conducted by U.S. Geological Survey (Weeks et al. 1974).

7.2.3 Other Abiotic-Abiotic Effects

Because the level of resolution of the model is fairly coarse in some places, the aggregation sometimes masks finer details that have been addressed by some of the baseline studies. For example, interactions between soil physical and chemical characteristics are not brought out strongly in the model, although they are implied by a number of flows: photosynthesis (flow 7) and percoloation (flow 38) are indirectly related to soil characteristics, either physical or chemical. Although these interrelationships are not quantified by the model, they are discussed in Volume IV, Chapter 2, of this report. Similarly, interactions between microenvironmental parameters are not handled in detail by the model, though they are implicit in some of the flows. For example, flows 28, 32, 33, 34, 36, and 37 deal with microenvironmental parameters, but do not explicitly quantify many important aspects of the microenvironment. Some of these aspects are discussed in Volume IV, Chapter 1, of the final report and are summarized in the time-series graphs of Appendix B.

In addition, certain oil shale development activities are expected to mix the soil profile and change soil chemistry on Tract C-b. The effects of these alterations would be felt primarily on the vegetation, as discussed in the next section.

7.3 Abiotic-Biotic Interrelationships

Four airborne perturbations - sulfur emissions, oxidants, fluoride emissions, and trace elements - will affect terrestrial plant growth. Although four specific processes are identified in the term plant growth (translocation to shoots and roots, and transpiration from the upper and lower soil layers), the general process called growth integrates all the sub-processes, including photosynthesis and respiration. The last two have been identified separately in the model. Sulfur emissions would result in decreased photosynthesis and increased respiration, with an overall net effect of reduced plant growth. The same might be said of the effects of the other airborne pollutants on terrestrial plant growth. Aboveground and belowground litter decomposition would also be affected by unmitigated sulfur emissions.

Fluorides could also have an effect on terrestrial animal growth and on the tissues themselves as fluoride accumulated in the tissues. Also affecting terrestrial animal growth would be certain trace elements associated with oil shale development. Terrestrial animal movement and reproduction would be impacted by noise and activity, as would the general habitat of animals. Animal reproduction includes courtship and mating behavior, so this process is subject to disturbance in the higher vertebrates, particularly those that indulge in elaborate courtship activities. Immigration and emigration into and out of the area also would be affected by human activity. Another development product, transmission lines and pipelines would alter general animal habitat.

Water-borne effects on the biota would include decreased growth of aquatic plants, vertebrate animals, and invertebrate animals. This phenomenon would be associated with sedimentation and altered surface water flows.

Other interrelationships not quantified by the model are the effects of soil characteristics on vegetation by species or type of cover. Microenvironmental effects on plant species and vegetation types are similarly not handled in detail by the model. However, these are discussed in Volume IV, Chapters 1 and 2, of this report. Specifically, some of these are the effects of the mixed soil profile on rehabilitation for revegetation of the disturbed areas, and altered soil chemistry effects on terrestrial plant growth and revegetation attempts.

7.4 Biotic-Biotic Interrelationships

Most of the abiotic effects impinging upon the biota of the environment of the Tract C-b environmental system will be felt through interactions among the biota themselves. For example, disturbed vegetation associated with man's activities in the area will affect the general habitat of plants and animals. It is difficult to say at this time how widespread the effect would be or to what degree specific plants or animals would be affected. The interrelationships displayed in Figure 6-2 and 6-3 now become valuable for tracing the effects of abiotic disturbances through the entire ecosystem. Plant growth, a process that integrates several other subprocesses, and which is affected by several of the development factors, in turn directly affects the accumulation of plant biomass. If the growth processes are seriously impeded, the resulting loss of production, particularly of grazing species, might well affect the terrestrial animal movements and biomass accumulation. Grazing animals will move to where the forage is.

From a long-term perspective subtle changes in plant growth could result in a type of plant succession in which palatable species were replaced by unpalatable, but hardier, species. Similarly, revegetation of disturbed areas must be considered carefully in the light of herbivores that might use these areas. This is a two-edged problem, because if species that are palatable to deer or cattle, or to other herbivores, are planted, an influx of animals could result in overgrazing. On the other hand, species that are not desirable might keep desirable animals out. Perturbations that effect terrestrial animal growth or movement could also affect predator movements. Too much accumulation of toxic substances in plants or in the soil, resulting in the population decline or death of small mammals, could affect the raptor populations as well as other predators. It is difficult to determine just how some of these higher order interrelationships would be affected, unless some of these relationships were carefully quantified through a well conceived monitoring program.

In the aquatic system, some of the same basic principles apply. Alteration of the chemical or suspended particulate concentrations would undoubtedly affect plant and animal growth and ultimately species distributions, stability, and diversity. A lowered water table would very likely mean that less water was available for plant species that exist on an already dry site. This, too, could affect terrestrial plant distribution and long-term succession.

Many animal behavioral patterns are not clearly addressed by the model. For example, various types of predation are not covered, such as raptor effects on other birds and rabbits, and the effects of coyotes and bobcats on rodents and other small mammals. Behavioral patterns of large mammals, such as deer and elk, are not explicitly included either. Some suggestions for dealing with these highly visible large mammals are presented in Chapter 8.

7.5 Summary

Of the more than 900 effects identified in Figure 5-7, this chapter addresses 28 major effects, using as a criterion for selection their relatability to oil shale development. These effects can be direct, indirect, or both, and their interactions among other components of the ecosystem can be traced by using the system diagrams of Figure 6-2 and 6-3. Only a few of the broad implications are discussed in this chapter.

8 UTILIZATION IN MONITORING AND MITIGATION

8.1 Introduction

The value of any model can be judged in part by its usefulness. The usefulness of the conceptual model of the Tract C-b environmental system developed in this volume remains to be determined. This model, and the steps that went into building it, provide a summary of about 2½ years of baseline studies in the environment of Tract C-b. Volume II of the final baseline study report describes, summarizes, and discusses the hydrology of the tract. Volume III does the same with the meteorology, and Volume IV discusses the ecology. Building on these early volumes and bringing to the study a different perspective, Volume V has attempted to build diagrammatically a conceptual model of the Tract C-b environmental system. This chapter discusses in broad terms the utilization of this model for long-term monitoring program and mitigation of any perturbations connected with oil shale development.

8.2 Monitoring

As mentioned earlier, three criteria were used to determine which major interrelationships out of an infinite variety should be considered in this volume. The first criterion, relatability to oil shale development, was addressed in Chapter 7. The other two criteria, observability and measurability, should be the criteria for setting up a monitoring program.

8.2.1 General Suggestions

Two basic questions should be answered in designing a monitoring program. The first is what to monitor, and the second, how to monitor it. The fundamental objective of a monitoring program should be to maximize the amount of useful, relevant information while minimizing the cost required to get that information. It is hoped that this model will help the user address the first question within the framework of the stated objective. A little extra time spent in planning the monitoring program using the techniques and material presented in this volume should pay rich dividends in information gained at lower relative cost per unit of information.

Furthermore, a monitoring program should be responsive to, and suggestive of, a total mitigation program for oil shale development.

By this is meant simply that in planning a monitoring program, key environmental interrelationships are chosen. One of the criteria for chosing these key relationships is that they might be impacted by oil shale development, despite a careful mitigation program. In this sense, monitoring is responsive to the mitigation program in that it monitors those key relationships that have already been identified as potential receptors of the unmitigated impact. At the same time, a good monitoring program will anticipate other sensitive relationships in the environmental system that should be monitored in the event that mitigation is necessary. In other words, a good monitoring program should provide an early warning system in areas where mitigation was originally thought to be unnecessary.

Table 7-1 identifies 14 separate effect receptors comprising 19 environmental system processes that control the flow of matter and energy through the system. These processes and other receptors constitute a relatively small proportion of the total. This is a starting point for a monitoring program. Much of the potential damage to the environment lies in various plant growth processes, animal growth processes, and animal movement processes. Monitoring programs should focus on key species or other indicators of how these processes are affected. Plant and animal tissue analysis is an important part of such a program. Monitoring the transport media, i.e., the air and water, is also very important. The model should help planners determine which types of foreign matter to monitor in these transport media. Litter decomposition, a very difficult process to monitor, could yield a great deal of information about deposition of various types of particulates in the system. Aquatic plant and animal growth are also important indicator processes that might be monitored. Although there is very little surface water on the Tract C-b, downstream monitoring could provide information on sedimentation and other types of pollutants that fall on the terrestrial system and are transported by runoff.

Also important to consider are some of the components and processes that were not studied during the baseline period but which are identified in this volume as being conceptually important. The dotted lines in Figures 2-1 and 2-9 and the blank spaces in Table F-7 of the User's Reference clearly point out some of the gaps that need to be filled. By using the diagrams and matrix developed in this volume, a monitoring program can be designed to provide information about key components, information that the baseline studies have not provided. Although not all the blanks need to be filled, enough of them should be filled to provide the minimal information necessary to understand the functioning of Tract C-b.

This leads directly to another suggestion for monitoring: attempting to monitor biological processes rather than ecosystem components. Most processes are extremely difficult to measure, and the cost:benefit ratios would have to be considered carefully. But ecological processes are the key to the transfer of energy to the system, and as the state-of-the-art advances, we can and should study the processes in more and more detail.

Another specific suggestion is to rely more heavily on experimental designs that attempt to correlate the behavior of different ecosystem components with one another. Statistical correlations, although technically not cause-and-effect relationships, provide excellent insight into ecological interactions, often where they are not suspected. The interrelationships and the interconnections described and diagrammed in Volume V can provide many clues for establishing a monitoring program. Such a program should monitor many different components and or processes simultaneously in such a way that the data lend themselves to sound statistical correlation and regression analyses. These analyses in themselves provide further insights into the expansion and modification of monitoring. For example, if a relationship between two different ecosystems' components is suspected, a year or two of simultaneously monitoring those components and the dynamics of their behavior through the year will generally either support or refute the hypothesis that the two components are interrelated. If they are interrelated, the monitoring program might be modified to look at these interrelationships in more detail, particularly if they are associated with man's activities in the area. If the hypothesis is rejected, further study of the interrelationship between those two components would probably not be necessary, and the monitoring of their behavior could be safely phased out.

Yet another facet would be to monitor more closely, at shorter intervals, the time-varying behavior of many of the ecosystem components. This suggestion ties in with the one above of monitoring the behavior of those system variables that at present are represented only by estimates, the dotted lines in Figure 2-1 through 2-9.

Two general criteria that might be considered as guidelines for the program are (1) monitoring highly visible elements of the environmental system and (2) monitoring those elements of the system which are not necessarily visible, but which are ecologically, biologically, or otherwise intrinsically important to the system. We have been discussing the second criterion above. An example of the first criterion might be deer and elk, which have great emotional impact in the area. For example, one hypothesis that was formulated by a principle investigator was: When work begins on the oil shale development, deer will disperse initially, but then will gradually come back as they will become used to man's activities in the area. If this hypothesis is true, it could have serious ramifications among hunters in the area the first year or two when the herds decline. Knowing that this possiblity exists and perhaps publicizing it might mitigate hunter outcries.

This is the type of behavioral pattern that is not addressed explicitly by the model. Roadcount information often can determine migrational timing and general patterns of concentration throughout the Tract. Elk are another highly visible species that might need to be considered in a monitoring program. Not much work was done with elk pellet counts on the Tract, and no counts were made on the perimeter of the Tract, where elk are known to occur. These are some specific examples of the need to consider highly visible species as well as factors in the system that are biologically significant.

8.2.2 A Team Approach To Designing A Program

To design a sound, thorough monitoring program at a minimum cost using this volume and the rest of the baseline study report would require a small group of ecologists from complementary disciplines to meet together and go over these materials in sufficient detail to identify what specific components and processes need to be monitored. Using the diagrams presented here, such a team could trace the biological and ecological effects of different types of environmental perturbations through the system, as demonstrated in Chapters 6 and 7, and systematically keep track of the important factors as they move through the system. If done properly, this process of systematically tracing effects through the system and keeping track of how these things are affected, should produce a nuclear set of components and processes that would be the most important to watch.

Once the monitoring program is designed, it is then possible to go back into the conceptual model in this volume and, by tracing through the diagrams, determine how much more information the monitoring program will provide about components of the system and processes that are not monitored.

8.3 Mitigation

As mentioned above, the monitoring program should both lead directly into mitigation and be responsive to mitigation. The detailed development plan (C-b 1976a) and its modification (C-b 1977) address the mitigation requirements very carefully. Unless a monitoring program shows that certain types of environmental perturbations are causing problems in the system, there do not appear to be any new requirements for mitigation other than those proposed at present.

8.4 Extending The Utility Of The Model

Up to this point the model of the Tract C-b environmental system has been purely conceptual with no attempt at numerical implementation. Appendix E briefly discusses how this conceptual model might be numerically extended to improve its utility. Although a complete ecosystem-level numerical simulation model is probably beyond the immediate scope of a monitoring and mitigation program, models of some of the subsystems could be very useful for guiding the monitoring of the program in the future and for anticipating mitigation needs.

For example, several deer herd population numerical simulation models have been developed throughout the country, many of them in the state of Colorado. These models incorporate such things as road-kill aspects, fencing and other barriers, habitat control measures, weather factors, etc. Adaptation of one or more of these models to the Tract C-b deer herd could be used to study various alternative controls that would be necessary to mitigate an anticipated increase of deer road-kill as the human population of the area increases.

Many air diffusion models are also available. Any one of these could be used as a starter to predict ground level concentrations of fugitive dust with various levels of emission controls. If these meteorological models were coupled with a model of oil shale rehabilitation and stabilization, different alternative treatments could be studied by simulating the behavior of the oil shale pile fugitive dust and the reclamation procedures over time.

Hydrology is another area where modeling has been used and could be used again to couple the abiotic components of the system to some of the biotic components, such as the relationships between groundwater and vegetational change. Weeks et al. (1974) have already developed a simulation model for the groundwater hydrology in the Piceance Basin. U.S. Geological Survey people are working on extending and improving this model to study mine dewatering and reinjection problems. The groundwater model could also be used to study fluoride leaching from dams, shale piles, and possibly from retorts themselves.

Many ecological models are appearing in the open literature, and undoubtedly some of these would be adaptable with little modification to subsystems of Tract C-b. A strong modeling effort coupled with a sound monitoring program could provide precise, accurate, validated models that would lend a great deal of credibility to ecological predictions and thus the analysis of impacts of man's activities on Tract C-b.

8.5 Summary

This chapter utilizes the background and techniques developed in earlier chapters to discuss the planning of the monitoring program. It is suggested that the mitigation plans outlined by the oil shale development program are sufficient at this time.

C-b Oil Shale Project. 1976a. Detailed development plan and related materials. Ashland Oil, Inc. and Shell Oil Co. Unnumbered pages.

C-b Oil Shale Project. 1976b. First year environmental baseline program: Annual summary and trends report. Ashland Oil, Inc. and Shell Oil Company. 546 pp.

C-b Oil Shale Venture. 1977. Modifications to detailed development plan. Ashland Oil, Inc. and Occidental Oil Shale, Inc. Unnumbered pages.

Weeks, John B., George H. Leavesley, Frank A. Welder, and George J. Saulnier, Jr. 1974. Simulated effects of oil-shale development on the hydrology of Piceance Basin, Colorado. Geological Survey Paper 908, U.S. Government Printing Office, Washington, D.C. 84 pp.

Woodwell, G. M. and R. H. Whittaker. 1968. Primary production in terrestrial ecosystems. Amer. Zoologist 8(1):19-30.

APPENDIX A

APPENDIX A ECOSYSTEM COMPONENTS: RATIONALE FOR CHOICES OF DRIVING AND STATE VARIABLES AND ECOSYSTEM RESPONSE UNITS

A.1 Introduction

This appendix contains the rationale behind, and the details of, the state and driving variable selections. The general approach was to identify virtually all structural components of the Tract C-b system, group these according to some functional or taxonomic criteria, and aggregate as many as possible into a set of components that was smaller and easier to work with.

Selecting ecosystem components alternated with selecting important ecosystem processes. The initial list of selected components might not accommodate important processes, and the initial list of processes might require disaggregating some of the components to provide the necessary detail.

The iterations, however, are not explicit here; rather, the development of the component list is presented in Appendix A and the development of the interrelation networks is explained in Appendix C.

A.2 General Inventory

Data from the baseline studies were collected on a variety of ecosystem components and, in many cases, included measuring several attributes of one component (Table A-1). Most of these measurements were on state variables, some on driving variables, and very few on ecosystem processes.

A.2.1 Structural Components

Early lists of structural components of ecosystems in Tract C-b were provided in the baseline annual report (Shell 1976b). The present elaboration includes components and groups developed through discussion and analysis during the year intervening between that report and this final summary. Table A-2 represents an attempt to define the total list of ecosystem components that might possibly be significant in the oil shale development Tract. Such a comprehensive list permits careful scrutiny of anything within the natural ecosystem that might possibly be affected by

Table A-1.

GENERAL INVENTORY OF ECOSYSTEM COMPONENTS (STATE AND DRIVING VARIABLES) AND THE MEASURED ATTRIBUTE(S) OF EACH COMPONENT

COMPONENT	ATTRIBUTE	FUNCTIONAL GROUP
Air	Temperature Relative humidity Potential evaporation Trace metals Short-term CO_2 levels Short-term particulate levels Annual SO_2 isopleths Annual particulate isopleths Temperature extremes	Atmosphere
Precipitation	Frost depths Snow loads	
Noise		
Solar radiation		
Fish	Average length Average weight Population estimates Length-frequency species Growth Distribution of spp.	Fish
Benthos	Biomass Densities Relative distribution Species diversity (artificial substrate)	Aquatic Invertebrates

Table A-1

(CONTINUED)

COMPONENT	ATTRIBUTE	FUNCTIONAL GROUP
Periphyton	Accumulation Primary productivity Relative distribution	Periphyton
Water	Temperature Dissolved O_2 Conductivity pH TDS (total dissolved solids) Total alkalinity. Total hardness Cations (5) Anions (10) Nutrients (4)	
Coliforms (3) Streptococci Pathogens		Microbiological organisms
Sediment	Moisture T.K.N. (total Kjeldahl Nitrogen) C.O.D. (chemical O_2 demand) Volatile solids Grain size analysis (Tyler screen) Heavy metals (Spectrographic screen)	

Table A-1

(CONTINUED)

COMPONENT	ATTRIBUTE	FUNCTIONAL GROUP
Small Mammals	Density Biomass Reproduction Activity index Food habits Age class	Small mammals
Reptiles	Relative abundance Density Biomass Reproduction Food habits Age class	Reptiles
Arthropods	Relative abundance Species diversity Trophic level	Terrestrial Invertebrates
Current Live Standing Crop		Herbs
Standing Dead Crop		
Litter and Prostrate Dead		Herbs & Shrubs
Mountain Mahogany	Decomposition (leaves)	
Serviceberry	Stem length	

Table A-1

(CONTINUED)

COMPONENT	ATTRIBUTE	FUNCTIONAL GROUP
Big Sagebrush Pinon-Juniper (woodland) Big Sage (bottomland sage communities) Standing Crop 8 spp. shrub shrub saplings	Shoot growth Lateral shoot development Cellulose control Litterfall	
Perennial Grasses & other major herbs	Phenophases (8)	Herbs
Coyote	Scent stations	Med-size Mammals
Cottontail	Abundance	
Deer	Pellet-group counts Browse utilization Mortality Age-class Composition	Large-size Mammals
Soil	Physical characteristics Nutrients Radioactivity Moisture Temperature	Soil

Table A-1

(CONTINUED)

COMPONENT	ATTRIBUTE	FUNCTIONAL GROUP
	Depth	
	Density	
	Water content	
Songbirds	Density	Birds
Waterfowl	Average bird-use days	
Nocturnal Raptors	Relative abundance	
Raptorial Prey Items		
All Species	Diversity indices	

Table A-2a

A LISTING OF MAJOR ABIOTIC COMPONENTS, STATE AND DRIVING VARIABLES

Major Group	Variables	Forest Upland	General Upland				General Bottomland						Aquatic	
		Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-Wood	Sage-Brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Driving Variables	Precipitation	x	x	x	x	x	x	x	x	x	x	x		
	Temperature	x	x	x	x	x	x	x	x	x	x	x	x	x
	Wind	x	x	x	x	x	x	x	x	x	x	x	x	x
	Solar Radiation	x	x	x	x	x	x	x	x	x	x	x	x	x
State Variables	Soil Temperature	x	x	x	x	x	x	x	x	x	x	x		
	Soil Water	x	x	x	x	x	x	x	x	x	x	x		
	Soil Chemistry	x	x	x	x	x	x	x	x	x	x	x		
	Canopy Temperature	x	x	x	x	x	x	x	x	x	x	x		
	Water Temperature												x	x

Table A-2b

MATRIX OF AUTOTROPHS IN FOUR ECOSYSTEM TYPES

		Forest Upland	General Upland				General Bottomland						Aquatic	
Major Group	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Trees	Box Elder										x			
	Douglas Fir	x												
	Narrowleaf Cottonwood										x			
	Pinyon Pine	x	x		x									
	Rocky Mtn. Juniper	x												
	Siberian Elm	x	x											
	Utah Juniper	x	x											
Shrubs	Antelope Bitterbrush	x	x		x									
	Big Sagebrush	x	x		x				x	x				
	Chokecherry					x								
	Currant					x								
	Four-winged Saltbush			x										
	Gambel's Oak	x	x											
	Golden Currant					x								
	Greasewood							x		x				
	Horsebrush	x	x		x									
	Mormon Tea	x												
	Mtn. Mahogany	x	x											
	Oregon Grape	x												
	Prickly Pear	x	x		x									

Table A-2b

(CONTINUED)

		Forest Upland	General Upland				General Bottomland						Aquatic	
Major Group	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Shrubs (Continued)	Rabbitbrush	x	x		x		x							
	Rock Spirea	x												
	Rubber Rabbitbrush	x	x				x	x	x			x		
	Serviceberry	x	x		x									
	Shadscale			x										
	Silver Buffaloberry										x			
	Skunkbush					x								
	Smooth Currant					x								
	Snowberry	x	x		x				x					
	Utah Serviceberry	x			x									
	Wild Rose					x								
	Willow										x			
	Winter Fat				x									
	Yucca glauca	x	x											
Annual Grasses & Forbs	Annual Spurge													
	Baby Blue-eyes	x	x		x	x								
	Barnyard Grass											x		
	Bee Plant							x						
	Cheatgrass	x	x	x	x			x	x			x		
	Chorispora						x							

Table A-2b

(CONTINUED)

		Forest Upland	General Upland				General Bottomland						Aquatic	
Major Group	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Annual Grasses & Forbs (Continued	Collomia		x	x										
	Common Sunflower										x			
	Evening Primrose	x												
	Fairy Candelaria	x	x						x					
	False Flax		x											
	Foxtail Barley											x		
	Golden Smoke								x		x			
	Goosefoot	x	x	x	x				x			x		
	Gumbo Lily	x	x	x										
	Japanese Brome											x		
	Knotweed (2spp.)		x		x									
	Mentzellia		x											
	Microsteris	x	x		x									
	Miner's Candle	x	x									x		
	Much-branched Gayophytum	x	x		x							x		
	Nodding Eriogonum													
	Pigweed											x		
	Prickly Lettuce	x										x		
	Rabbit's-Foot Grass											x		
	Russian Thistle			x				x	x			x		
	Stickseed	x	x					x	x			x		

Table A-2b

(Continued)

		Forest Upland	General Upland				General Bottomland						Aquatic	
Major Group	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Annual Grasses & Forbs (Continued)	Summer Cypress		x					x						
	Tansy Mustard	x	x		x			x	x			x		
	Tobacco		x											
	Tumble Mustard		x											
	White Dreba	x	x											
	White Pigweed											x		
	White Sweet Clover										x			
	Wing-fruited Sweet Verbena								x					
	Yellow Evening Primrose										x			
	Yellow Sweet Clover											x		
Perennial Graminoids	Baltic Rush										x			x
	Blue-bunch Wheatgrass	x	x											
	Blue Grama	x	x						x					
	Bluegrass	x												
	Cattail													x
	Common Reed										x			x
	Crested Wheatgrass	x	x		x			x						
	Darnel											x		
	Great Basin Wild Rye							x		x				
	Horsetail										x			

Table A-2b

(CONTINUED)

		Forest Upland	General Upland				General Bottomland						Aquatic	
Major Group	Species	Pinyon-Juniper	Chained Range-Land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Perrenial Graminoids (Continued)	Indian Ricegrass	x	x	x	x				x			x		
	Junegrass	x	x		x									
	Kentucky Bluegrass	x	x								x			
	Larkspur		x		x									
	Little Ricegrass	x							x			x		
	Mountain Brome					x								
	Mountain Grass	x	x		x									
	Needle-and-Thread	x	x		x				x					
	Nodding Brome	x												
	Orchard Grass											x		
	Prairie Bulrush										x			
	Red Top											x		
	Scouring Rush										x			
	Sedges (4 spp.)													x
	Sheed Fescue	x	x		x									
	Slender Wheatgrass		x	x				x	x					
	Sloughgrass										x			
	Smooth Brome							x						
	Spikerush													x
	Squirreltail Grass	x	x						x					

Table A-2b

(CONTINUED)

		Forest Upland	General Upland				General Bottomland						Aquatic	
	Species	Pinyon-Juniper	Chained Range-Land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Perrenial Graminoids (Continued)	Sunsedge	x	x		x									
	Timothy										x			
	Western Wheatgrass	x	x	x	x			x	x			x		
	Agrostis alba										x			
Perennial Forbs	Actinea	x	x											
	Alfalfa										x			
	Alum Root		x											
	Aster	x	x		x			x						
	Aster Adscendens					x								
	Balsam Root	x	x		x									
	Bastard Toadflax	x	x		x							x		
	Beard Tongue		x	x										
	Biennial Wormhood										x			
	Biscuitroot	x	x		x									
	Blue Clematis					x								
	Blue Lettuce										x	x		
	Canada Thistle											x		
	Cancer Root				x									
	Checker Mallow										x			

Table A-2b
(CONTINUED)

		Forest Upland	General Upland				General Bottomland						Aquatic	
	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Perennial Forbs (Continued)	Cinquefoil		x											
	Clover		x		x									
	Colorado Bedstraw			x										
	Cryptantha	x	x											
	Curly-cup Gumweed											x		
	Daisy Fleabane	x	x		x									
	Dandelion	x	x		x				x			x		
	Death Camas	x	x		x									
	Dock											x		
	Double Bladderpod	x	x		x				x					
	Easter Daisy	x	x		x									
	Evening Star		x									x		
	False Dandelion	x	x		x							x		
	False Gromwell			x										
	False Pennyroyal													
	False Solomon's Seal										x			
	False Yarrow	x	x											
	Fireweed										x			
	Fremont Penstemon	x	x		x									
	Glaucous Aster			x										

Table A-2b

(CONTINUED)

		Forest Upland	General Upland				General Bottomland						Aquatic	
	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Perennial Forbs (Continued)	Goat's Beard	x	x											
	Golden Aster		x											
	Golden Ragwort	x	x		x				x					
	Goldenrod										x			
	Goldenweed	x	x		x									
	Green Sage						x	x				x		
	Hawksbeard	x	x		x									
	Horehound		x											
	Horseweed										x			
	Hymenopappus	x	x											
	Indian Paintbrush				x									
	Kentrophyta Milk Vetch	x	x	x	x									
	Long-leaved Phlox	x	x		x				x					
	Lupine	x	x		x									
	Mare's Tail													x
	Mariposa Lily	x	x		x									
	Marsh Elder										x			
	Mat Penstemon		x		x									
	Meadow Goldenrod										x			
	Meadow Milk Vetch	x	x		x									

Table A-2b
(CONTINUED)

		Upland Forest	General Upland				General Bottomland						Aquatic	
	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Perennial Forbs (Continued)	Moss Phlox	x	x		x									
	Mtn. Peppergrass	x						x	x			x		
	Narrow-leaved Gromwell		x											
	Nodding Microseris		x											
	Nuttall's Sunflower										x			
	Nuttall's Yellow Violet								x					
	Oval-leaved Wild Buck-wheat	x	x											
	Painted Milk Vetch	x	x											
	Pasque Flower					x								
	Pasture Sage			x					x					
	Pearly Everlasting						x							
	Peppergrass					x			x					
	Phacelia			x										
	Prickly Gilia	x	x											
	Puccoon		x											
	Purshia Milk Vetch	x	x		x									
	Pussytoes	x	x		x									
	Ragweed											x		
	Ragwort	x	x											
	Rock Cress	x	x		x									

Table A-2b

(CONTINUED)

		Forest Upland	General Upland				General Bottomland						Aquatic	
Group	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Perennial Forbs (Continued)	Rocky Mtn. Milk Vetch	x	x		x									
	Sagebrush Buttercup	x	x		x									
	Sagewort	x	x					x	x					
	Sand Dropseed								x					
	Scarlet Gilia	x	x		x				x					
	Scarlet Globe Mallow	x	x		x			x	x					
	Seaside Arrowgrass											x		
	Shore Buttercup										x			
	Short-rayed Alkali Aster		x											
	Showy Milkweed										x	x		
	Sow Thistle											x		
	Speedwell										x	x		
	Spoon-leaved Milk Vetch										x	x		
	Spreading Dogbane													
	Snakeweed	x	x		x									
	Spurge											x		
	Stephanomeria	x												
	Stinging Nettle										x			
	Sugarbowls					x								
	Sulphur Flower	x	x											

Table A-2b
(CONTINUED)

		Forest Upland	General Upland				General Bottomland						Aquatic	
Species Groups	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Perennial Forbs (Continued)	Sweet Vetch		x		x									
	Tassell-flower Brickell-brush			x										
	Thistle	x		x					x					
	Tule													x
	Tumble Mustard	x										x		
	Twistflower	x												
	Umbrellawort	x												
	Utah Daisy Fleabane	x	x		x			x						
	Watercress												x	
	Watson Penstemon					x								
	Western Gromwell		x											
	Western Virgin's Bower										x	x		
	Western Wallflower	x	x											
	Wild Buckwheat	x	x	x										
	Wild Flax		x											
	Wild Hops										x			
	Wild Licorice										x	x		
	Wild Onion				x									
	Winged Eriogonum	x	x		x									
	Yarrow											x		

Table A-2b

(CONTINUED)

		Forest Upland	General Upland				General Bottomland						Aquatic	
Species Groups	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
	Plankton												x	x
	Periphyton												x	x

Table A-2c

MATRIX OF MAMMALS IN FOUR ECOSYSTEM TYPES

			Forest Upland	General Upland				General Bottomland						Aquatic	
Major Group	Species Groups	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Fye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Small Mammals	Shrews	Water Shrew										x		x	x
		Dwarf Shrew													
		Vagrant Shrew		x								x	x		
		Merriam's Shrew													
		Masked Shrew		x	x							x	x	x	x
	Bats	Townsend's Big-eared Bat	x	x	x	x	x	x	x	x	x	x	x		
		Pallid Bat	x	x	x	x	x	x	x	x	x	x	x		
		Spotted Bat													
		Silver-haired Bat	x	x											
		Hoary Bat	x	x											
		Big Brown Bat	x	x											
		Western Pipistrella													
		Long-legged Myotis	x	x											
		California Myotis													
		Small-footed Myotis													
		Fringed Myotis													
		Long-eared Myotis	x	x											
		Little Brown Myotis	x	x											
		Brazilian Free-tailed Bat													

Table A-2c

(CONTINUED)

			Forest Upland	General Upland				General Bottomland						Aquatic	
Major Group	Species Groups	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Small Mammals	Squirrels	Richardson's Gr. Squirrel							x						
		Golden Mantled Gr. Squirrel	x	x	x	x	x	x	x	x	x				
	Mice	Deer Mouse	x	x	x	x	x	x	x	x	x	x	x		
		Pinon Mouse	x	x											
		House Mouse											x		
		Western Jumping Mouse					x								
		Apache Pocket Mouse		x		x							x		
	Rats	Bushy-tailed Woodrat	x	x			x		x						
	Voles	Meadow Vole										x			
		Montane Vole			x	x	x								
		Long-tailed Vole			x	x	x					x			
		Sagebrush Vole			x	x	x								
	Gophers	Northern Pocket Gopher		x	x	x						x	x		
	Chipmunks	Least Chipmunk	x	x	x	x	x	x	x	x	x	x			
		Colorado Chipmunk	x	x	x	x	x								
		Uinta Chipmunk	x	x	x	x	x								

Table A-2c

(CONTINUED)

			Forest Upland	General Upland				General Bottomland						Aquatic	
Major Group	Species Groups	Species	Pinyon-Juniper	Chained Range-land	Bunch-Grass	Sage-Brush	Mixed Mt. Shrub	Rabbit-Brush	Grease-wood	Sage-brush	Wild Rye	Rip-arian	Agri-cultural Meadow	Stream	Pond & Marsh
Medium-Sized Mannals	Rabbits	White-tailed Jackrabbit	x	x	x	x	x	x	x	x	x	x	x		
		Desert Cottontail	x	x	x	x	x	x	x	x	x	x	x		
	Rodents	Yellow-bellied Marmot											x		
		Beaver													
		Muskrat													
		Porcupine													
	Carnivores	Coyote	x	x	x	x	x	x	x	x	x	x	x		
		Raccoon	x									x	x	x	x
		Ermine		x			x				x	x			
		Long-tailed Weasel	x	x		x	x			x		x	x		
		Badger			x	x	x			x			x		
		Striped Skunk										x	x		
		Bobcat	x	x	x	x	x	x	x	x	x	x			
Large Mammals	Ungulates	Elk	x	x	x	x	x								
		Mule deer	x	x	x	x	x	x	x	x	x	x	x		

Table A-2d

MATRIX OF BIRDS IN FOUR ECOSYSTEM TYPES

FUNCTIONAL GROUP	SPECIES	FORESTED UPLAND	NON-FORESTED UPLAND	GENERAL BOTTOMLAND	AQUATIC	FALL	WINTER	SPRING	SUMMER
OMNIVORES	Mallard			x	x	x	x	x	x
	Gadwall				x	x	x	x	x
	Pintail			x	x	x			
	Green-Winged Teal			x	x	x	x	x	x
	Blue-Winged Teal			x	x	x	x	x	x
	American Wigeon			x	x	x	x	x	
	Northern Shoveler			x	x	x			
	Cinnamon Teal			x	x			x	x
	Wood Duck			x	x			x	
	Ring-Necked Duck			x	x			x	
	Common Goldeneye			x	x		x	x	
	Barrow's Goldeneye			x	x		x		
	Bufflehead			x	x		x		
	Red-Breasted Merganser			x	x		x		
	Sage Grouse		x	x		x			
	Sandhill Crane		x	x	x	x			
	American Coot			x	x	x		x	x
	Mourning Dove	x	x	x		x		x	x
	Broad-Tailed Hummingbird	x	x	x					x
	Common Flicker	x	x	x		x	x	x	x
	Horned Lark	x		x		x	x		x

Table A-2d

(CONTINUED)

FUNCTIONAL GROUP	SPECIES	FORESTED UPLAND	NON-FORESTED UPLAND	GENERAL BOTTOMLAND	AQUATIC	FALL	WINTER	SPRING	SUMMER
OMNIVORES (Cont.)	Stellar's Jay	x		x		x	x		x
	Scrub Jay	x	x	x		x	x	x	x
	Pinyon Jay	x				x	x	x	x
	Black-Billed Magpie	x	x	x		x	x	x	x
	Clark's Nutcracker	x	x	x		x	x	x	x
	Common Crow					x			
	Black-Capped Chickadee	x		x		x	x	x	x
	Mountain Chickadee	x	x	x		x	x	x	x
	Plain Titmouse	x	x					x	x
	White-Breasted Nuthatch	x		x		x	x	x	x
	Red-Breasted Nuthatch	x				x	x		
	American Robin	x	x	x		x	x	x	x
	Townsend's Solitaire	x	x	x		x	x	x	x
	Hermit Thrush	x	x						x
	Mountain Bluebeard	x	x	x		x		x	x
	Water Pipit							x	
	Bohemian Waxwing	x	x				x		
	Starling			x		x		x	x
	Bobolink								x
	Western Meadowlark			x		x		x	x
	Red-Winged Blackbird			x		x	x	x	x

Table A-2d

(CONTINUED)

FUNCTIONAL GROUP	SPECIES	FORESTED UPLAND	NON-FORESTED UPLAND	GENERAL BOTTOMLAND	AQUATIC	FALL	WINTER	SPRING	SUMMER
OMNIVORES (Cont.)	Yellow-Headed Blackbird					x			
	Brewer's Blackbird			x		x		x	x
	Brown-Headed Cowbird			x					x
	Black-Headed Grosbeak	x							x
	Evening Grosbeak	x	x	x			x	x	
	House Finch	x	x	x		x	x	x	x
	Gray-Crowned Rosy Finch		x				x		
	Black Rosy Finch		x				x		
	Brown-Capped Rosy Finch		x				x		
	Pine Siskin	x		x		x			x
	American Goldfinch					x			
	Red Crossbill	x	x				x	x	
	Green-Tailed Towhee	x	x	x		x		x	x
	Rufous-Sided Towhee	x	x			x	x		x
	Savannah Sparrow	x	x			x			
	Lark Bunting								x
	Vesper Sparrow	x	x	x		x		x	x
	Sage Sparrow								x
	Black-Throated Sparrow	x							x
	Dark-Eyed Junco	x	x	x			x	x	
	Gray-Headed Junco	x	x	x		x	x	x	x

Table A-2d

(CONTINUED)

FUNCTIONAL GROUP	SPECIES	FORESTED UPLAND	NON-FORESTED UPLAND	GENERAL BOTTOMLAND	AQUATIC	FALL	WINTER	SPRING	SUMMER
OMNIVORES (Cont.)	Tree Sparrow			x		x	x	x	
	Chipping Sparrow	x	x	x		x		x	x
	Brewer's Sparrow	x	x	x		x			x
	White-Crowned Sparrow	x		x		x			x
	Song Sparrow	x		x		x	x	x	x
INSECTIVORES	Kildeer			x	x			x	x
	Common Snipe			x	x	x	x	x	x
	Spotted Sandpiper			x	x			x	x
	Solitary Sandpiper			x	x	x			x
	Lesser Yellowlegs			x	x	x			x
	Greater Yellowlegs			x	x			x	
	American Avocet			x	x				x
	Wilson's Phalarope			x	x			x	x
	Poor-Will								x
	Common Nighthawk	x	x			x			x
	White-Throated Swift	x	x	x					x
	Williamson's Sapsucker								x
	Hairy Woodpecker	x				x			x
	Downy Woodpecker	x				x	x		x
	Cassin's Kingbird			x					x

Table A-2d

(CONTINUED)

FUNCTIONAL GROUP	SPECIES	FORESTED UPLAND	NON-FORESTED UPLAND	GENERAL BOTTOMLAND	AQUATIC	FALL	WINTER	SPRING	SUMMER
INSECTIVORES (Cont.)	Ash-Throated Flycatcher	x	x						x
	Say's Phoebe		x	x		x		x	x
	Gray Flycatcher	x	x			x			x
	Western Flycatcher		x			x			
	Dusky Flycatcher	x							
	Western Wood Pewce	x		x				x	x
	Olive-Sided Flycatcher			x					x
	Barn Swallow			x		x			x
	Cliff Swallow	x	x	x		x			x
	Violet-Green Swallow	x	x	x		x			x
	Tree Swallow	x	x	x					x
	Rough-Winged Swallow			x					x
	House Wren	x		x		x			x
	Rock Wren		x	x		x		x	x
	Canyon Wren					x		x	
	Sage Thrasher					x			x
	Blue-Gray Gnatcatcher	x	x	x		x		x	x
	Ruby-Crowned Kinglet		x			x			
	Solitary Vireo	x	x			x			x
	Red-Eyed Vireo								x
	Warbling Vireo	x							x

Table A-2d

(CONTINUED)

FUNCTIONAL GROUP	SPECIES	FORESTED UPLAND	NON-FORESTED UPLAND	GENERAL BOTTOMLAND	AQUATIC	FALL	WINTER	SPRING	SUMMER
INSECTIVORES (Cont.)	Orange-Crowned Warbler								x
	Virginia's Warbler		x	x					x
	Yellow Warbler								x
	Yellow-Rumped Warbler	x	x	x		x			x
	Black-Throated Gray Warbler	x	x	x		x			x
	Townsend's Warbler	x				x			x
	Common Yellowthroat			x		x			x
	MacGillivrau's Warbler		x						x
	Wilson's Warbler								x
	Western Tanager								x
CARNIVORES	Pied-Balled Grebe			x	x				x
	Turkey Vulture	x	x	x		x		x	x
	Goshawk	x							x
	Cooper's Hawk	x							x
	Sharp-Shinned Hawk	x							x
	Marsh Hawk		x	x		x	x	x	x
	Rough-Legged Hawk			x		x	x	x	
	Red-Tailed Hawk	x	x	x		x	x	x	x
	Golden Eagle	x	x	x		x	x	x	x
	Bald Eagle			x	x		x	x	

Table A-2d

(CONTINUED)

FUNCTIONAL GROUP	SPECIES	FORESTED UPLAND	NON-FORESTED UPLAND	GENERAL BOTTOMLAND	AQUATIC	FALL	WINTER	SPRING	SUMMER
CARNIVORES (Cont.)	American Kestrel	x	x	x		x	x	x	x
	Prairie Falcon		x	x		x	x	x	
	Barn Owl			x		x			
	Screech Owl	x	x	x			x		x
	Great Horned Owl	x	x	x		x	x	x	x
	Long-Eared Owl	x	x				x		x
	Short-Eared Owl						x		x
	Snowy Owl						x		
	Saw-Whet Owl	x							x
	Pygmy Owl	x							x
	Belted Kingfisher			x		x		x	x
	Common Raven	x	x	x		x	x	x	x
	Northern Shrike			x		x	x	x	
	Loggerhead Shrike						x	x	

man-induced changes in the system. Effectively, it is an inventory that simply provides a point of departure in aggregating functional roles in the ecosystem. Driving variables are separated from state variables; both are selected according to their functional significance.

Columns in Table A-2 are habitat types that were mapped in the annual report (Shell 1976b). These 13 habitat types are identified according to topographic position, i.e., upland or bottomland, etc. Entries in the table indicate the presence of a given variable in a particular habitat. Table A-2a lists abiotic components.

Table A-2b lists the autotrophic, or plant, components in the major habitat types. These plants are grouped according to growth forms such as trees, shrubs, annual grasses and forbs, perennial graminoids (grasses and grass-like plants), and perennial forbs. The list of species does not necessarily represent every plant that occurs in Tract C-b, but only the more common species. As many as several hundred species may be found on a square mile in the area. An X in one of the columns of Table A-2b indicates the major habitat community, or communities, in which the species is found. This listing of plants is subject to addition. Common names are listed here, but scientific names are found in Volume IV, Appendix B.

Major mammals of the Tract C-b system are listed in Table A-2c. They are grouped into arbitrary categories of small, medium, and large with respect to body size, and then into other categories. Many of the mammals are wide-ranging and would be found at some time on all of the habitat types mapped in the first-year baseline report. However, many other mammals are primarily restricted to one or a few of the habitat types and are thus noted.

More than 250 species of birds have been identified on Tract C-b. Table A-2d summarizes groups of birds according to major habitat categories.

A full census has not been made of all organism groups. However, arthropods have been sampled and some groupings are listed in Table A-2e. Reptiles and amphibians are present on Tract C-b but have not been thoroughly censused. Fish are present in the streams of the area and have been censused.

A.3 Spatial Units

The concept of macro-units, meso-units, and micro-units of space on the Tract was discussed in the annual report (Shell 1976b). Selection of spatial units of reasonable size requires a trade-off between too much detail and not enough. The overall

Tract C-b system is not homogeneous, so some selection had to be made. Micro-units occur at the spatial niche level of the system, e.g., tree piles, eyries, lateral draws, litter hummocks, springs and seeps, etc. To study or to conceptualize even a small sample of these micro-units is beyond the scope of the present project.

At the other extreme, macro-units can be defined at the regional level, e.g., Piceance Basin, Book Cliffs, Colorado River Valley, etc. Within each of these broad regional areas several physiognomic classifications may be defined, e.g., ridges and upland plateaus, slopes, bottomland floodplains, and streamcourses. Any of these classifications is too broad to be much use in determining the response of the Tract C-b ecosystem to man's impact.

Neither the limited nor the broad extremes are entirely suitable for assessing environmental impact, the first because of heavy sampling requirements, and the second because it is basically abiotic and would reflect only gross physiognomic impacts. The units of vegetation noted in Table A-2 at first appear to be a logical choice of degree of spatial resolution or detail. This is because the vegetation provides an excellent link between the abiotic components of the ecosystem and the heterotrophic components. Fourteen vegetative types or habitat types were identified in the annual report (Shell 1976b, pp. 299-359), and have been linked to major topographical features.

The plant community types can be further grouped into ecosystem response units (Table A-3). Two types of upland systems, two types of bottomland systems, and two types of aquatic systems are noted in the ecosystem response units identified. Upland areas are subdivided into forest and nonforested (general upland) categories. All bottomland vegetation types except the meadows are combined. Meadows are treated separately because, although they make up only a very small component of the Tract C-b system, the dynamics and importance of this component are disproportionate to its size. Similarly, streams, ponds, and marshes make up only a small proportion of the surface acreage of the Tract, but these are important habitats. For the final conceptualization, the stream and pond units were aggregated into a single aquatic unit.

One plant community, the Douglas fir type, is omitted from our classification because it occurs in the study area only in isolated stands and not in any significant quantity. Thus, although it is mapped, it does not enter into the vegetation types in Table A-3.

To summarize, the functional spatial units of the system-ecosystem response units comprise one or more plant communities. To these are added two broad categories of disturbed sites: upland and bottomland rehabilitated sites.

Table A-3

AGGREGATIONS OF PLANT COMMUNITIES INTO ECOSYSTEM RESPONSE UNITS FOR A CONCEPTUAL MODEL OF THE C-b SYSTEM

PLANT COMMUNITY LIST	ECOSYSTEM RESPONSE UNITS
PINYON- JUNIPER	UPLAND FOREST
CHAINED RANGELAND	GENERAL UPLAND
BUNCHGRASS	
SAGEBRUSH	
MOUNTAIN SHRUB	
RABBITBRUSH	GENERAL BOTTOMLAND
GREASEWOOD	
SAGEBRUSH	
WILDRYE	
RIPARIAN	
MEADOW	MEADOW
STREAM	STREAM
POND/MARSH	POND

A.4 Relationships--Ecosystem Components and Response Units

As a next step in the conceptualization process, the variables listed in Table A-2 are combined into broad categories for purposes of model development. Thus, in Table A-4 three types of abiotic variables, six types of autotrophic variables, and eight types of heterotrophic variables are listed. These are cross-classified conceptually with seven ecosystem response units.

The variables listed in Table A-4 are a second step in aggregating those listed in Table A-2, yet more functional detail has been introduced. Thus, soil temperature is defined at two soil depth levels, and soil water content is defined at two soil depth levels and for a groundwater layer. A soil carbon-to-nitrogen ratio is defined for the two soil levels as an index to growth potential for plants and microbial organisms. The five major plant groups defined in Table A-2b are subdivided into anatomical portions of live shoots, standing dead, and live roots. A generalized aquatic vegetation is introduced as phytoplankton at this stage of conceptualization, and aboveground and belowground litter are also defined. The animal groups of Tables A-2c through A-2e are aggregated into taxonomic categories and then subdivided into functional categories. This listing of variables is simply a step in the conceptualization process. The purpose is to define more functionally oriented groups than were derived in Table A-2.

Table A-4 has seven ecosystem response units listed in columns. Five of these are taken from the listing in Table A-3 (aquatics is combined), and two new units have been added to consider oil shale development in the conceptual model. These are rehabilitated sites located either in the upland or in the bottomland. Table A-4 thus provides a conceptual structure, without entries, for classifying variables in different ecosystem response units. It is another step in deriving a list of driving variables and state variables.

A.5 Relationships--Conceptual Components and the Data

As discussed above, and noted in Table A-1, a large number of variables were measured in the baseline studies in late 1974, all of 1975, and much of 1976. These data have been presented in Volumes II through IV (C-b 1977b). Many of these data are summarized in Appendix B in uniform, time-series graphs. Grouping or categorizing these variables required further definition of the variables listed in Table A-4. Successive reductions and elaborations resulted in an almost final list of driving variables for the Tract C-b system conceptual model (Table A-5).

The first four driving variables represent external climatic factors which affect the system, but which in turn are not affected

Table A-4

A SIMPLIFIED LISTING OF VARIABLES AND ECOSYSTEM COMPLEXES OF TRACT C-b

			Upland Forests	General Upland	General Bottom-Land	Meadow	Aquatic	Upland Rehabilitated	Bottom-Land Rehabilitated
Abiotic	Soil Temperature-	level 1							
		level 2							
	Soil Water -	level 1							
		level 2							
		Alluvial water table							
	Soil C:N-	level 1							
		level 2							
Autotrophs	Annuals	live							
		dead							
		root							
	Grass-	live							
		dead							
		root							
	Forb-	live							
		dead							
		root							
	Shrub-	live							
		dead							
		root							
	Tree-	live							
		dead							
		root							
	Phytoplankton								
	Litter	above ground							
		below ground							
Heterotrophs	Arthropod-	predator							
		scavenger							
		omnivore							
		herbivore							
		parasite							
	Reptile-	lizard							
		snake							
	Amphibian-								
	Fish-	predator							
		omnivore							
		herbivore							
	Bird-	waterfowl							
		raptor							
		passerine							
		upland game							
	Small Mammal-	predator							
		omnivore							
		herbivore							
	Medium Mammal-	predator							
		omnivore							
		herbivore							
	Large Mammal-	predator							
		omnivore							
		herbivore							
	Cattle-								

Table A-5

PRELIMINARY FINAL LIST
OF DRIVING VARIABLES ON TRACT C-b

1. Precipitation
2. Air temperature
3. Wind
4. Solar radiation
5. Forest cutting decision
6. Cattle grazing decision
7. Sulfurous emissions
8. Nitrogenous emissions
9. Oxidant emissions
10. Trace metal emissions
11. Carbon monoxide emissions
12. Water vapor emissions
13. Fugitive dust
14. Noise
15. Human activity

by what will happen in the Tract C-b system. Air temperature as used here represents temperature above the plant canopy, approximately at a 2-m height. Wind represents that above the plant canopy. The driving variables for cattle grazing and forest cutting represent management decisions and are effectively "on-off switches." The remaining variables largely represent expected effects from oil shale development.

Analysis of the list of structural elements in Table A-2 and the conceptual condensation of Tables A-3 and A-4 into spatial subdivisions and functional groups of divisions leads to a disaggregated list of state variables for the Tract C-b conceptual model (Table A-6). Some of these variables were studied in depth, and others were not measured. Appendix B relates the driving and state variables developed in Appendix A to actual data from the baseline studies. Final lists of driving and state variables for the Tract C-b conceptual model are provided in Chapter 2 of the text and in the User's Reference (Appendix F).

Table A-6

DISAGGREGATED LIST OF
STATE VARIABLES OF THE TRACT C-b

1. Cattle numbers
2. Deer numbers
3. Insectivore bird numbers
4. Omnivore bird numbers
5. Carnivore bird numbers
6. Predator numbers
7. Rabbit numbers
8. Rodent numbers
9. Reptile numbers
10. Arthropod numbers
11. Cattle weight
12. Deer weight
13. Insectivore bird weight
14. Omnivore bird weight
15. Carnivore bird weight
16. Predator weight
17. Rabbit weight
18. Rodent weight
19. Reptile weight
20. Arthropod weight
21. Annual shoot biomass
22. Perennial grass shoot biomass
23. Perennial forb shoot biomass
24. Live shrub biomass
25. Live tree biomass
26. Dead annual biomass
27. Dead perennial grass biomass
28. Dead perennial forb biomass
29. Dead shrub biomass
30. Dead tree biomass
31. Live annual root biomass
32. Live perennial grass root biomass
33. Live perennial forb root biomass
34. Live shrub root biomass
35. Live tree root biomass
36. Aboveground litter biomass
37. Belowground litter biomass
38. Upper soil layer temperature
39. Lower soil layer temperature
40. Snow water
41. Upper soil layer water
42. Lower soil layer water
43. Groundwater surface
44. Terrestrial surface area
45. Aquatic vertebrate numbers
46. Aquatic invertebrate numbers
47. Aquatic vertebrate weight
48. Aquatic invertebrate weight
49. Aquatic rooted plant biomass
50. Aquatic nonrooted plant biomass
51. Aquatic detritus biomass
52. Ice layer temperature
53. Water layer temperature
54. Ice layer volume
55. Water layer volume
56. Aquatic surface area

APPENDIX B

APPENDIX B TIME-SERIES DYNAMICS OF DRIVING AND STATE VARIABLES ON TRACT C-b

B.1 Introduction

One of the primary concerns of the ecosystem analyst is the behavior of ecosystem components and processes through time. By tracking time-variant behavior of several related components and processes it is often possible to infer cause-effect relationships through statistical analysis. Accurate cause-effect relationships are the foundation of any conceptual or simulation model.

However, even when statistical correlations are not determined, it is valuable to have information about how a given ecosystem component or process varies over time. If we can assume that a time-variant annual curve is somewhat representative of a norm for a given variable, then we can hypothesize certain interrelationships that affect the behavior of that curve.

To this end, nearly 500 time-series graphs of driving variables, state variables, and processes were identified in Volumes II through IV (C-b 1977b) and re-drawn in a standard format. These graphs constitute the heart of Appendix B.

B.2 Appendix B As An Information Base

Because of space limitations, certain units on the graphs are coded (Table B-1). In addition, each time series graph is cross-referenced to its original in the earlier volumes (Table B-2). The user can thus get a quick picture in this volume of how certain variables behave over time, and, if interested, he can quickly find the complete information in earlier volumes. The graphs themselves are found in Figure B-1.

Table B-1

KEY TO ABBREVIATIONS ON TIME-SERIES GRAPHS

ABBREVIATION	AREA OR UNITS
BG	Bunchgrass
BLSB	Bottomland Sagebrush
CPJR	Chained Pinyon-Juniper Rangeland
CSB	Canyon Sagebrush
MMS	Mixed Mountain Shrub
PJSS	Mixed Pinyon-Juniper/Sage/Shrub
PJWD	Pinyon-Juniper Woodland
RM	Riparian Meadow
UPSB	Upland Sagebrush
UPTS	Upland Transition

CFS	cubic feet per second
CO	dissolved oxygen
GE	ground elevation
Ha	hectare
MSL	mean sea level
PFD	pitfall day
PPM	parts per million
RH	relative humidity
T	transect
TDS	total dissolved solids
TL	trophic level

Table B-2

CROSS-REFERENCE OF TIME-SERIES GRAPHS WITH THE FIGURES AND TABLES FROM VOLUMES II, III, AND IV, SHOWING THE ORIGINAL DATA FROM WHICH THE TIME-SERIES GRAPHS WERE DRAWN

TIME-SERIES GRAPH NUMBER	ORIGINAL	
	VOLUME	FIGURE
1	IV	3-1-2
2	IV	3-1-3
3	IV	3-1-4
4	IV	3-1-5
5	IV	3-1-2
6	IV	3-1-2
7	IV	3-1-2
8	IV	3-1-2
9	IV	3-1-2
10	IV	3-1-3
11	IV	3-1-3
12	IV	3-1-3
13	IV	3-1-3
14	IV	3-1-3
15	IV	3-1-4
16	IV	3-1-4
17	IV	3-1-4
18	IV	3-1-4
19	IV	3-1-4
20	IV	3-1-5
21	IV	3-1-5
22	IV	3-1-5
23	IV	3-1-5
24	IV	3-1-5
25	IV	3-1-6
26	IV	3-1-6
27	IV	3-1-6
28	IV	3-1-6
29	IV	3-1-6
30	IV	3-1-6
31	IV	3-1-6
32	IV	3-1-6
33	III	Tab 3-5
34	III	Tab 3-5
35	III	Tab 3-5
36	III	Tab 3-5
37	IV	3-1-14
38	IV	3-1-14
39	IV	3-1-14
40	IV	3-1-14
41	III	Tab 7-15
42	III	Tab 3-37
43	III	Tab 3-37
44	IV	B-1-1
45	IV	Tab B-1-8
46	IV	Tab B-1-8
47	IV	Tab B-1-8
48	IV	Tab B-1-8
49	IV	Tab B-1-8
50	IV	Tab B-1-8
51	IV	Tab B-1-8
52	IV	Tab B-1-8
53	IV	Tab B-1-8
54	IV	Tab B-1-8
55	IV	Tab B-1-8
56	IV	Tab B-1-8
57	IV	Tab B-1-8
58	IV	Tab B-1-8

Table B-2 (Continued)

TIME-SERIES	ORIGINAL		TIME-SERIES	ORIGINAL	
GRAPH NUMBER	VOLUME	FIGURE	GRAPH NUMBER	VOLUME	FIGURE
59	IV	Tab B-1-8	90	IV	Tab 3-4-22
60	IV	Tab B-1-8	91	IV	Tab 3-4-22
61	IV	Tab B-1-8	92	IV	Tab 3-4-22
62	III	Tab 7-16	93	IV	Tab 3-4-22
63	III	Tab 7-16	94	IV	Tab 3-4-22
64	III	Tab 7-16	95	IV	Tab 3-4-22
65	III	Tab 7-16	96	IV	Tab 3-4-22
66	III	Tab 7-16	97	IV	Tab 3-4-22
67	III	Tab 7-17	98	IV	Tab 3-4-22
68	III	Tab 7-17	99	IV	Tab 3-4-22
69	IV	Tab 3-4-22	100	IV	Tab 3-4-22
70	IV	Tab 3-4-22	101	IV	Tab 3-4-22
71	IV	Tab 3-4-22	102	IV	Tab 3-4-22
72	IV	Tab 3-4-22	103	IV	Tab 3-4-22
73	IV	Tab 3-4-22	104	IV	Tab 3-4-22
74	IV	Tab 3-4-22	105	IV	Tab 3-4-22
75	IV	Tab 3-4-22	106	IV	Tab 3-4-22
76	IV	Tab 3-4-22	107	IV	Tab 3-4-22
77	IV	Tab 3-4-22	108	IV	Tab 3-4-22
78	IV	Tab 3-4-22	109	IV	Tab 3-4-22
79	IV	Tab 3-4-22	110	IV	Tab 3-4-22
80	IV	Tab 3-4-22	111	IV	Tab 3-4-22
81	IV	Tab 3-4-22	112	IV	3-4-7
82	IV	Tab 3-4-22	113	IV	B-4-4
83	IV	Tab 3-4-22	114	IV	B-4-4
84	IV	Tab 3-4-22	115	IV	B-4-3
85	IV	Tab 3-4-22	116	IV	B-4-3
86	IV	Tab 3-4-22	117	IV	B-4-1
87	IV	Tab 3-4-22	118	IV	B-4-2
88	IV	Tab 3-4-22	119	IV	3-4-12
89	IV	Tab 3-4-22	120	IV	3-4-12

Table B-2 (Continued)

TIME-SERIES GRAPH NUMBER	ORIGINAL	
	VOLUME	FIGURE
121	IV	3-4-12
122	IV	3-4-12
123	IV	3-4-12
124	IV	Tab B-4-24
125	IV	Tab B-4-24
126	IV	Tab B-4-27
127	IV	Tab B-4-27
128	IV	Tab B-4-28
129	IV	Tab B-4-28
130	IV	Tab B-4-29
131	IV	Tab B-4-29
132	IV	Tab B-4-25
133	IV	Tab B-4-25
134	IV	Tab B-4-25
135	IV	Tab B-4-25
136	IV	Tab B-4-25
137	IV	Tab B-4-25
138	IV	Tab B-4-25
139	IV	Tab B-4-25
140	IV	3-4-16
141	IV	3-4-16
142	IV	3-4-17
143	IV	3-4-17
144	IV	3-4-18
145	IV	3-4-18
146	IV	3-4-18
147	IV	3-4-18
148	IV	3-4-18
149	IV	3-4-18
150	IV	3-4-18
151	IV	3-4-18
152	IV	3-4-19
153	IV	3-4-19
154	IV	3-4-19
155	IV	3-4-19
156	IV	3-4-19
157	IV	3-4-19
158	IV	3-4-20
159	IV	3-4-20
160	IV	3-4-20
161	IV	3-4-21
162	IV	3-4-21
163	IV	3-4-21
164	IV	3-4-22
165	IV	3-4-22
166	IV	3-4-22
167	IV	3-4-22
168	IV	3-4-22
169	IV	3-4-22
170	IV	3-4-23
171	IV	3-4-23
172	IV	3-4-23
173	IV	3-4-23
174	IV	3-4-23
175	IV	3-4-24
176	IV	3-4-24
177	IV	3-4-24
178	IV	3-4-24
179	IV	3-5-10
180	IV	3-5-10
181	IV	3-5-10
182	IV	3-5-10

Table B-2 (Continued)

TIME-SERIES GRAPH NUMBER	ORIGINAL	
	VOLUME	FIGURE
183	IV	Tab 3-3-13 & 16
184	IV	Tab 3-3-13 & 16
185	IV	Tab 3-3-13 & 16
186	IV	Tab 3-3-13 & 16
187	IV	Tab 3-3-13 & 16
188	IV	Tab 3-3-13 & 16
189	IV	Tab 3-3-19 & 21
190	IV	Tab 3-3-19 & 21
191	IV	Tab 3-3-19 & 21
192	IV	Tab 3-3-19 & 21
193	IV	Tab 3-3-19 & 21
194	IV	Tab 3-3-19 & 21
195	IV	Tab 3-3-14 & 17
196	IV	Tab 3-3-14 & 17
197	IV	Tab 3-3-14 & 17
198	IV	Tab 3-3-14 & 17
199	IV	Tab 3-3-14 & 17
200	IV	Tab 3-3-14 & 17
201	IV	Tab 3-3-15 & 18
202	IV	Tab 3-3-15 & 18
203	IV	Tab 3-3-15 & 18
204	IV	Tab 3-3-15 & 18
205	IV	Tab 3-3-15 & 18
206	IV	Tab 3-3-15 & 18
207	IV	3-1-2
208	IV	3-1-3
209	IV	3-1-4
210	IV	3-1-5
211	IV	3-1-6
212	IV	3-1-6
213	IV	3-1-6
214	IV	3-1-6
215	IV	3-1-6
216	IV	3-1-6
217	IV	3-1-6
218	IV	3-1-6
219	IV	3-1-8
220	IV	3-1-8
221	IV	3-1-8
222	IV	3-1-8
223	IV	Tab B-5-9
224	IV	Tab B-5-9
225	IV	Tab B-5-9
226	IV	Tab B-5-9
227	IV	Tab 3-5-4
228	IV	Tab 3-5-4
229	IV	Tab 3-5-4
230	IV	Tab 3-5-4
231	IV	Tab B-5-7
232	IV	Tab B-5-7
233	IV	Tab B-5-7
234	IV	Tab B-5-7
235	IV	3-5-2
236	IV	3-5-2
237	IV	3-5-2
238	IV	3-5-2
239	IV	3-5-2
240	IV	3-5-2
241	IV	3-5-2
242	IV	3-5-2
243	IV	3-5-5
244	IV	3-5-5

Table B-2 (Continued)

TIME-SERIES GRAPH NUMBER	ORIGINAL	
	VOLUME	FIGURE
245	IV	3-5-5
246	IV	3-5-5
247	IV	3-5-3
248	IV	3-5-3
249	II	A-10
250	II	A-12
251	II	A-11
252	II	A-35
253	II	A-34
254	II	A-33
255	II	A-32
256	II	A-31
257	II	A-30
258	II	A-29
259	II	A-28
260	II	A-17
261	II	A-18
262	II	A-19
263	II	A-20
264	II	A-21
265	II	A-22
266	II	A-23
267	II	A-24
268	II	A-25
269	II	A-26
270	II	A-27
271	II	A-36
272	II	A-37
273	II	A-48
274	II	A-38
275	II	A-39
276	II	A-40
277	II	A-41
278	II	A-42
279	II	A-43
280	II	A-33
281	II	A-46
282	II	A-47
283	II	A-45
284	II	A-49
285	II	A-50
286	IV	3-4-10
287	IV	3-4-10
288	IV	3-4-10
289	IV	3-4-10
290	IV	3-4-10
291	IV	3-4-10
292	IV	3-4-11
293	IV	3-4-11
294	IV	3-4-11
295	IV	3-4-11
296	III	Tab 3-32
297	III	Tab 3-11
298	III	Tab 3-11
299	III	Tab 3-11
300	III	Tab 3-11
301	III	Tab 3-11
302	III	Tab 3-11
303	IV	Tab B-5-5
304	IV	Tab B-5-5
305	IV	Tab B-5-5
306	IV	Tab B-5-5

Table B-2 (Continued)

TIME-SERIES GRAPH NUMBER	ORIGINAL	
	VOLUME	FIGURE
307	II	3-54
308	II	3-54
309	II	3-54
310	II	3-54
311	II	3-54
312	II	3-54
313	II	3-54
314	II	3-54
315	II	3-17
316	II	3-17
317	II	3-17
318	II	3-16
319	II	3-16
320	II	3-16
321	II	A-6
322	II	A-7
323	II	A-8
324	II	A-2
325	II	A-3
326	II	A-1
327	II	A-15
328	II	A-14
329	II	3-12
330	II	3-13
331	II	3-12
332	II	A-16
333	II	A-13
334	IV	3-5-2
335	IV	3-5-2
336	IV	3-5-2
337	IV	3-5-2
338	IV	3-5-2
339	IV	3-5-2
340	IV	3-5-2
341	IV	3-5-2
342	IV	3-5-4
343	IV	3-5-3
344	IV	3-5-3
345	IV	3-5-6
346	IV	3-5-6
347	IV	3-5-6
348	IV	3-5-6
349	IV	3-5-6
350	IV	3-5-6
351	IV	3-5-6
352	IV	3-5-6
353	IV	3-5-7
354	IV	3-5-7
355	IV	3-5-7
356	IV	3-5-7
357	IV	3-5-8
358	IV	3-5-8
359	IV	3-5-9
360	IV	3-5-9
361	IV	3-5-9
362	IV	3-5-9
363	IV	3-5-9
364	IV	Tab B-5-1b
365	IV	3-5-5
366	IV	3-5-5
367	IV	3-5-5
368	IV	3-5-5

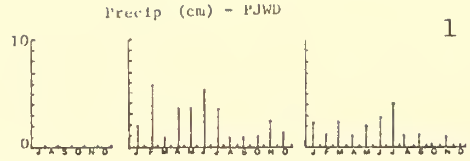
Table B-2 (Continued)

TIME-SERIES GRAPH NUMBER	ORIGINAL VOLUME	ORIGINAL FIGURE	TIME-SERIES GRAPH NUMBER	ORIGINAL VOLUME	ORIGINAL FIGURE
369	IV	Tab B-5-1b	400	IV	Tab B-5-1b
370	IV	Tab B-5-1b	401	IV	Tab B-5-1b
371	IV	Tab B-5-1b	402	IV	Tab B-5-1b
372	IV	Tab B-5-1b	403	IV	Tab B-5-1b
373	IV	Tab B-5-1b	404	IV	Tab B-5-1b
374	IV	Tab B-5-1b	405	IV	Tab B-5-1b
375	IV	Tab B-5-1b	406	IV	Tab B-5-1b
376	IV	Tab B-5-1b	407	IV	Tab B-5-1b
377	IV	Tab B-5-1b	408	IV	Tab B-5-1b
378	IV	Tab B-5-1b	409	IV	Tab B-5-1b
379	IV	Tab B-5-1b	410	IV	Tab B-5-1b
380	IV	Tab B-5-1b	411	IV	Tab B-5-1b
381	IV	Tab B-5-1b	412	IV	Tab B-5-1b
382	IV	Tab B-5-1b	413	IV	Tab B-5-1b
383	IV	Tab B-5-1b	414	IV	Tab B-5-1b
384	IV	Tab B-5-1b	415	IV	Tab B-5-1b
385	IV	Tab B-5-1b	416	IV	Tab B-5-1b
386	IV	Tab B-5-1b	417	IV	Tab B-5-1b
387	IV	Tab B-5-1b	418	IV	Tab B-5-1b
388	IV	Tab B-5-1b	419	IV	Tab B-5-1b
389	IV	Tab B-5-1b	420	IV	Tab B-5-1b
390	IV	Tab B-5-1b	421	IV	Tab B-5-1b
391	IV	Tab B-5-1b	422	IV	Tab B-5-1b
392	IV	Tab B-5-1b	423	IV	Tab B-5-1b
393	IV	Tab B-5-1b	424	IV	Tab B-5-1b
394	IV	Tab B-5-1b	425	IV	Tab B-5-1b
395	IV	Tab B-5-1b	426	IV	Tab B-5-1b
396	IV	Tab B-5-1b	427	IV	Tab B-5-1b
397	IV	Tab B-5-1b	428	IV	Tab B-5-1b
398	IV	Tab B-5-1b	429	IV	Tab B-5-1b
399	IV	Tab B-5-1b	430	IV	Tab B-5-1b

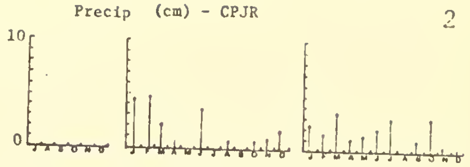
Table B-2 (Continued)

TIME-SERIES GRAPH NUMBER	ORIGINAL		TIME-SERIES GRAPH NUMBER	ORIGINAL	
	VOLUME	FIGURE		VOLUME	FIGURE
431	IV	Tab B-5-1b			
432	IV	Tab B-5-1b			
433	IV	Tab B-5-1b			
434	IV	Tab B-5-1b			
435	IV	Tab B-5-1b			
436	IV	Tab B-5-1b			
437	IV	Tab B-5-1b			
438	IV	Tab B-5-1b			
439	IV	Tab B-5-1b			
440	IV	Tab B-5-1b			
441	IV	Tab B-5-1b			
442	IV	Tab B-5-1b			
443	IV	Tab B-5-1b			
444	IV	Tab B-5-1b			
445	IV	Tab B-5-1b			
446	IV	Tab B-5-1b			
447	IV	Tab B-5-1b			
448	IV	Tab B-5-1b			
449	IV	Tab B-5-1b			
450	IV	Tab B-5-1b			
451	IV	Tab B-5-1b			
452	IV	Tab B-5-1b			
453	IV	Tab B-5-1b			
454	IV	Tab B-5-1b			
455	IV	Tab B-5-1b			

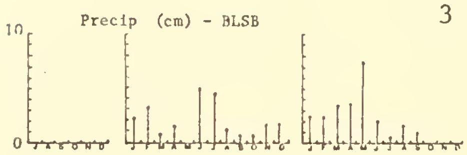
Figure B-1. TIME-SERIES DYNAMICS OF DRIVING AND STATE VARIABLES ON TRACT C-b. ABBREVIATION CODES ARE LISTED IN TABLE B-1. GRAPHS ARE CROSS-REFERENCED TO PRECEDING VOLUMES IN TABLE B-2. THE TOTAL TIME FRAME IS FROM JULY 1974 THROUGH DECEMBER 1976.


Precip (cm) - PJWD

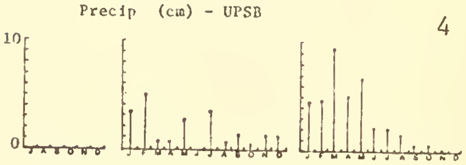
1


Precip (cm) - CPJR

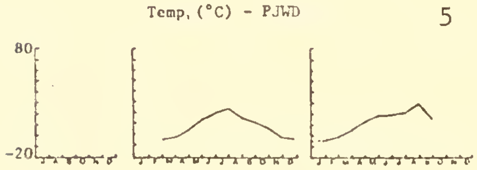
2


Precip (cm) - BLSB

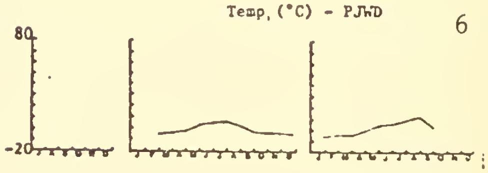
3


Precip (cm) - UPSB

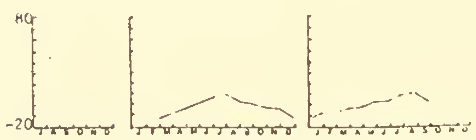
4


Temp, (°C) - PJWD

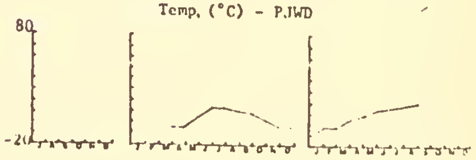
5


Temp, (°C) - PJWD

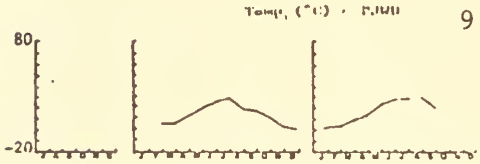
6


Temp, (°C) - PJWD

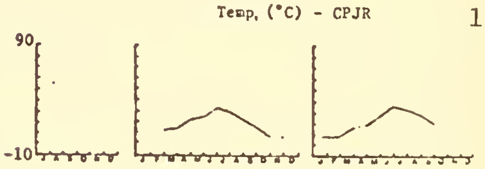
7


Temp, (°C) - PJWD

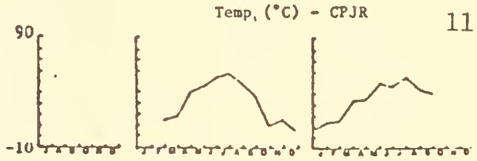
8


Temp, (°C) - PJWD

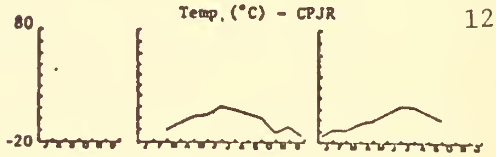
9


Temp, (°C) - CPJR

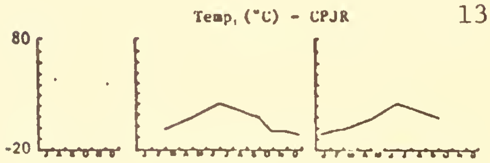
10


Temp, (°C) - CPJR

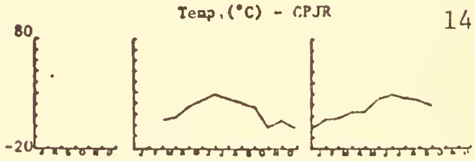
11


Temp, (°C) - CPJR

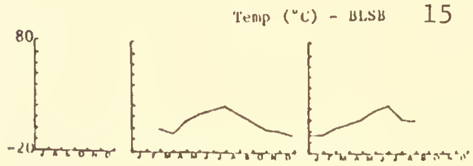
12


Temp, (°C) - CPJR

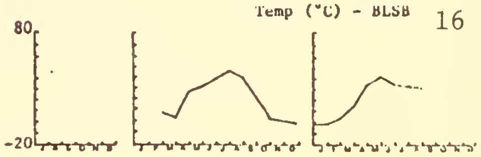
13


Temp, (°C) - CPJR

14

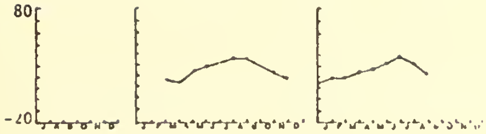

Temp (°C) - BLSB

15

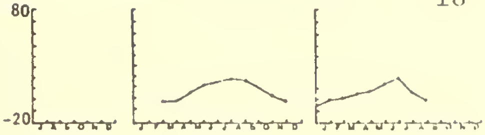

Temp (°C) - BLSB

16

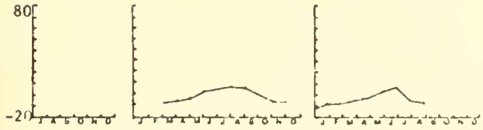
Temp (°C) - BLSB 17



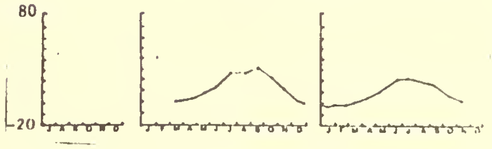
Temp (°C) - BLSB 18



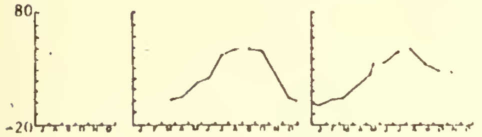
Temp (°C) - BLSB 19



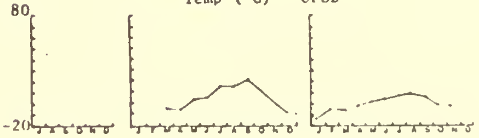
Temp (°C) - UPSB 20



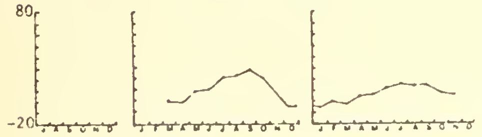
Temp (°C) - UPSB 21



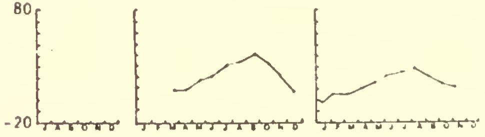
Temp (°C) - UPSB 22



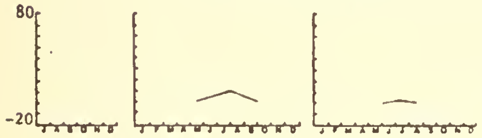
Temp (°C) - UPSB 23



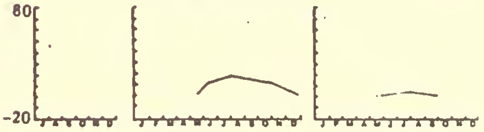
Temp (°C) - UPSB 24



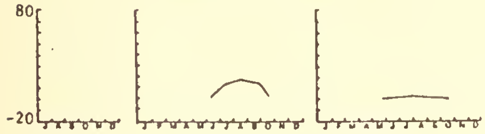
Temp (°C) - BLSB 25



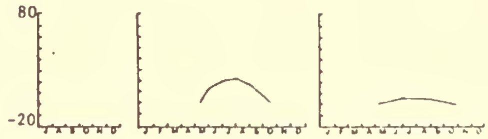
Temp (°C) - UPSB 26



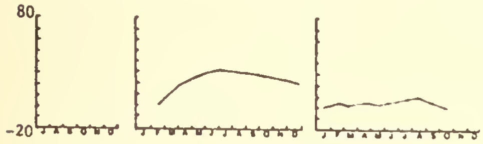
Temp (°C) - PJWD 27



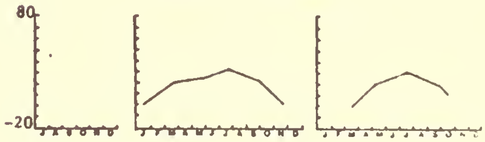
Temp (°C) - CPJR 28



Temp (°C) - BLSB 29

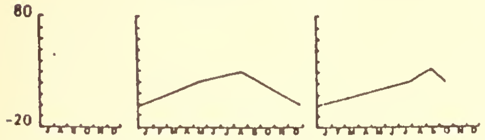


Temp (°C) - UPSB 30

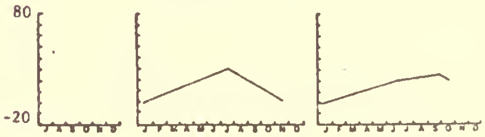


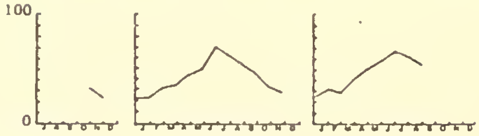
31

Temp (°C) - PJWD

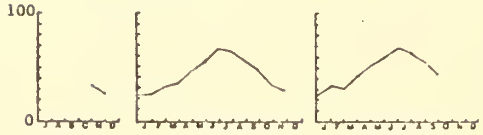


Temp (°C) - CPJR 32

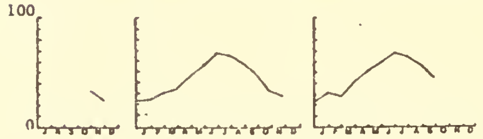




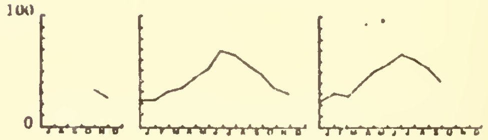
Mean Temp. (°F) - Met Tower, 8 ft 33



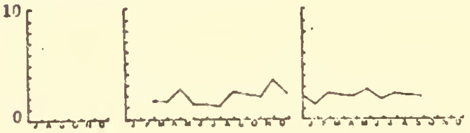
Mean Temp. (°F) - Met Tower, 30 ft 34



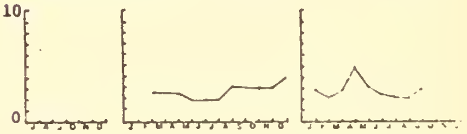
Mean Temp. (°F) - Met Tower, 100 ft 35



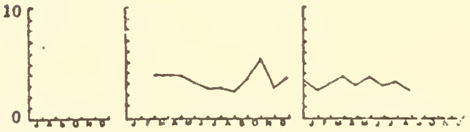
Mean Temp. (°F) - Met Tower, 200 ft 36



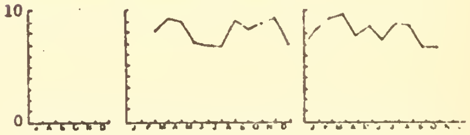
Wind Speed (km/hr) - PJWD 37



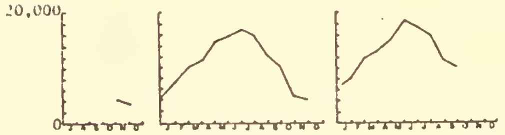
Wind Speed (km/hr) - BLSB 38



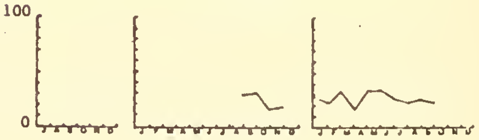
Wind Speed (km/hr) - CPJR 39



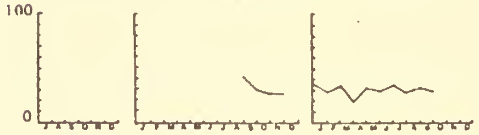
Wind Speed (km/hr) - UPSB 40



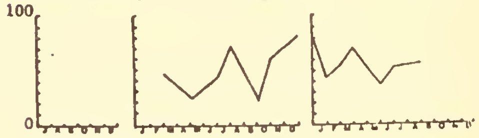
Solar Radiation (total Langleys, modified) - Trailor 023 41



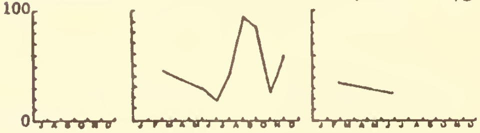
Environmental Noise (dbA above background) - Station 1 42



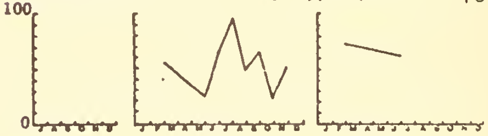
Environmental Noise (dbA above background) - Station 2 43



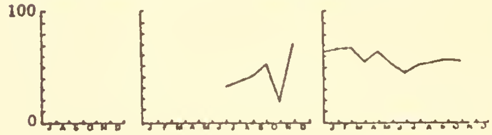
Mean Monthly RH (%) - Tract C-b 44



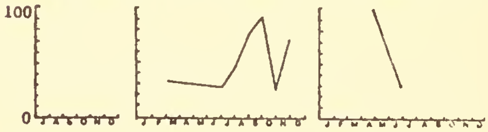
Mean Monthly RH (%) - Veg. Type 1, CPJR 45



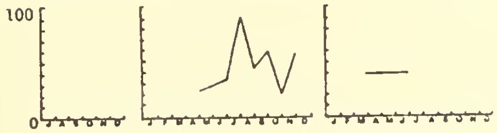
Mean Monthly RH (%) - Veg. Type 2, CPJR 46

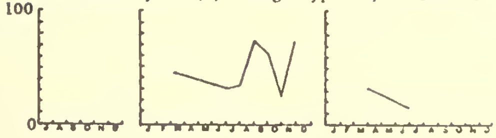


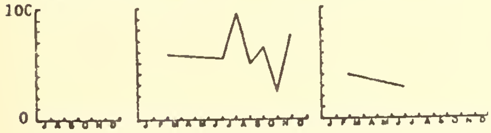
Mean Monthly RH (%) - Veg. Type 7, CPJR 47

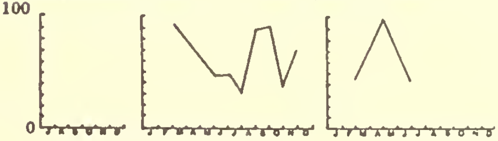


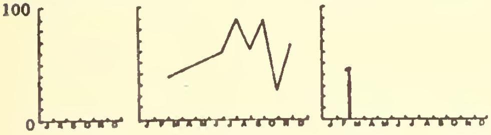
Mean Monthly RH (%) - Veg. Type 5, PJWD 48

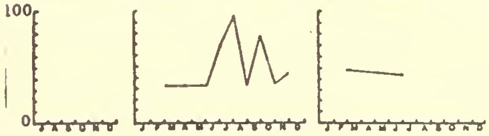

Mean Monthly RH (%) - Veg. Type 6, PJWD 49

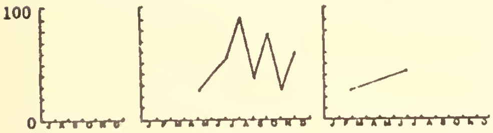

Mean Monthly RH (%) - Veg. Type 14, PJWD 50

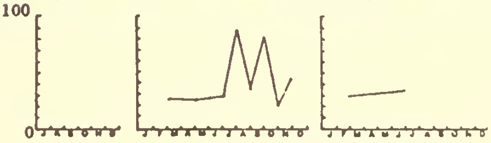

Mean Monthly RH (%) - Veg. Type 15, PJWD 51

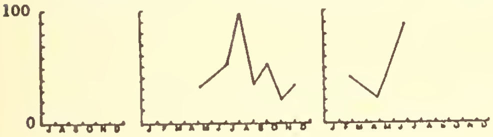

Mean Monthly RH (%) - Veg. Type 3, UPSB 52

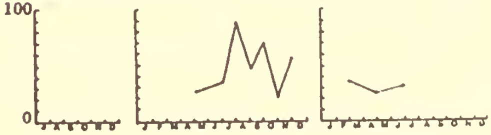

Mean Monthly RH (%) - Veg. Type 16, UPSB 53

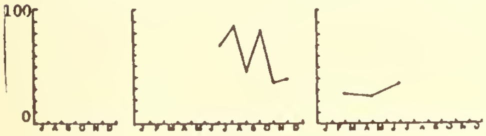

Mean Monthly RH (%) - Veg. Type 4, BLSB 54

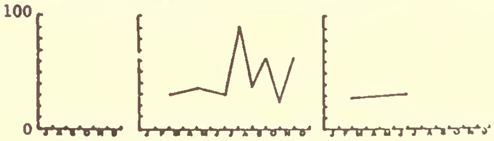

Mean Monthly RH (%) - Veg. Type 9, BLSB 55

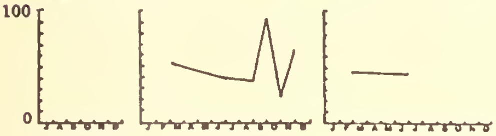

Mean Monthly RH (%) - Veg. Type 12, BLSB 56

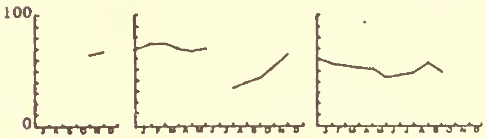

Mean Monthly RH (%) - Veg. Type 8, BG 57

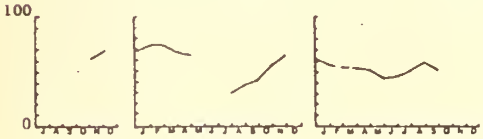

Mean Monthly RH (%) - Veg. Type 11, BG 58

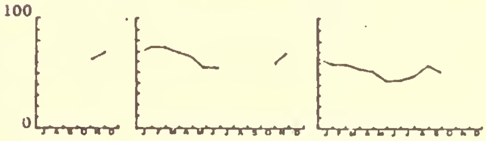

Mean Monthly RH (%) - Veg. Type 10, RB 59


Mean Monthly RH (%) - Veg. Type 13, MMS 60

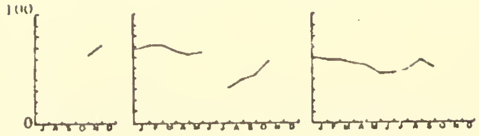

Mean Monthly RH (%) - Veg. Type 17, AW 61


RH (%) - Station 023, 8 ft 62

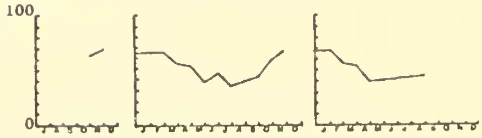

RH (%) - Station 023, 30 ft 63


RH (%) - Station 023, 100 ft 64

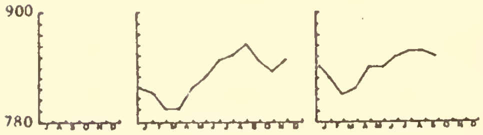
RH (%) - Station 023, 200 ft 65



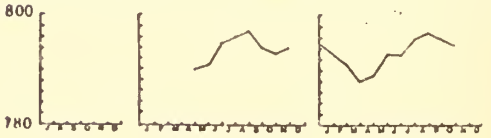
RH (%) - Station 024 66



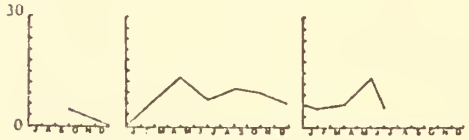
Barometric Pressure (mb) - Trailor 023 67



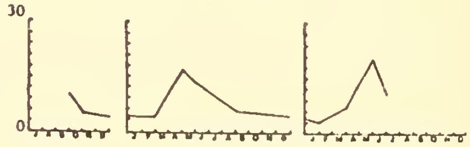
Barometric Pressure (mb) - Trailor 024 68



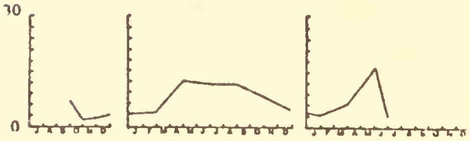
Bird Species (#/Ha) - T-1, CPJR 69



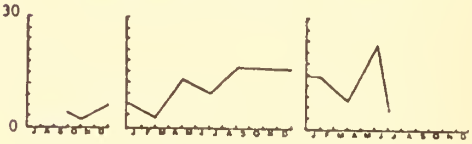
Bird Species (#/Ha) - T-2, RM 70



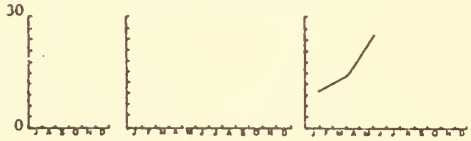
Bird Species (#/Ha) - T-3, BLSB 71



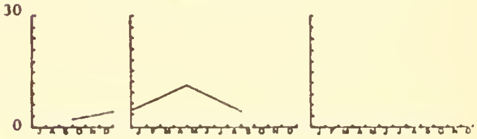
Bird Species (#/Ha) - T-4, PJWD 72



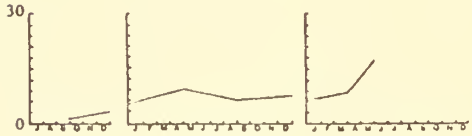
Bird Species (#/Ha) - T-5B, PJWD 73



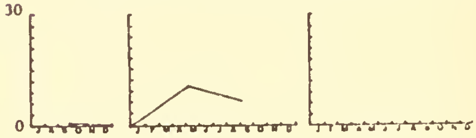
Bird Species (#/Ha) - T-5A, PJSS 74



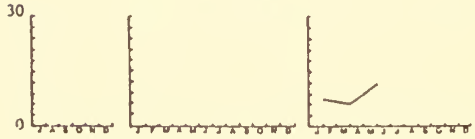
Bird Species (#/Ha) - T-6, CSB 75



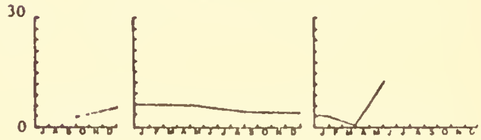
Bird Species (#/Ha) - T-7A, UPSB 76



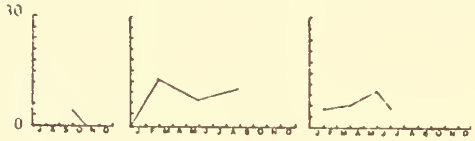
Bird Species (#/Ha) - T-7B, UPTS 77



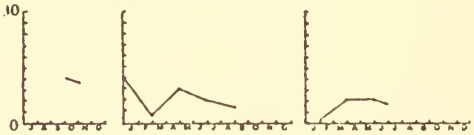
Bird Species (#/Ha) - T-8, MMS 78



Density (Birds/Ha) - T-2, RM 79

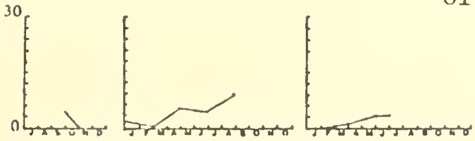


Density (Birds/Ha) - T-1, CPJR 80



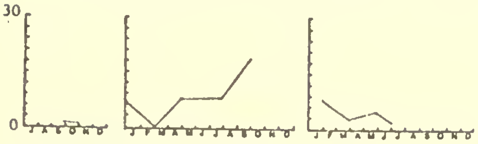
Density (Birds/Ha) - T-3, BLSB

81



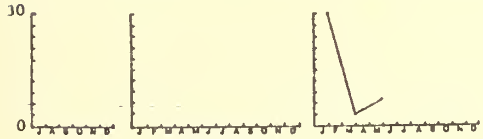
Density (Birds/Ha) - T-4, PJWD

82



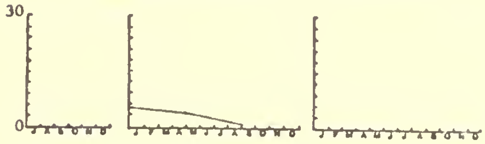
Density (Birds/Ha) - T-5B, PJWD

83



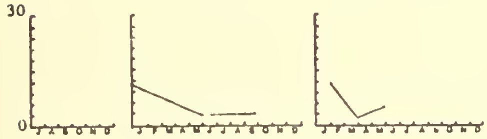
Density (Birds/Ha) - T-5A, PJSS

84



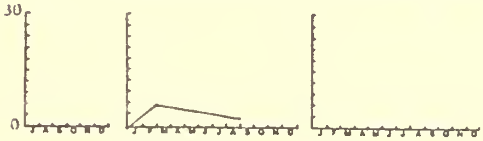
Density (Birds/Ha) - T-6, CSB

85



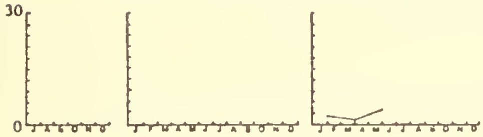
Density (Birds/Ha) - T-7A, UPSB

86



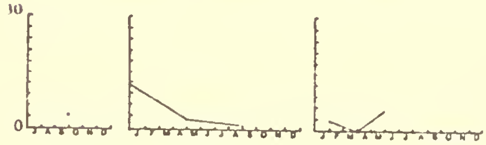
Density (Birds/Ha) - T-7B, UPTS

87



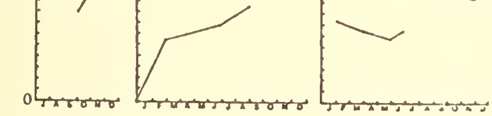
Density (Birds/Ha) - T-8, MMS

88



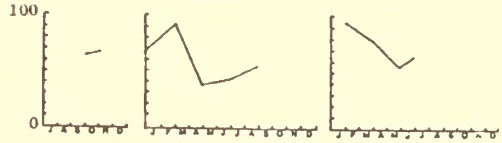
Avian Dominance Index (%) - T-1, CPJR

89



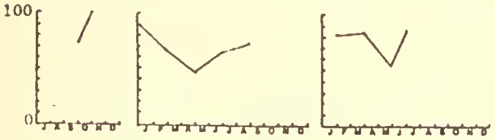
Avian Dominance Index (%) - T-2, RM

90



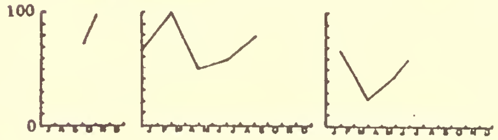
Avian Dominance Index (%) - T-3, BLSB

91



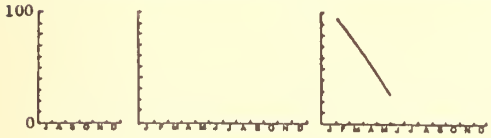
Avian Dominance Index (%) - T-4, PJWD

92



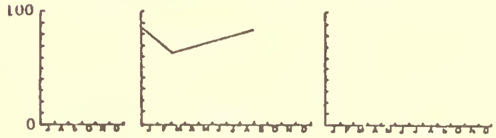
Avian Dominance Index (%) - T-5B, PJWD

93



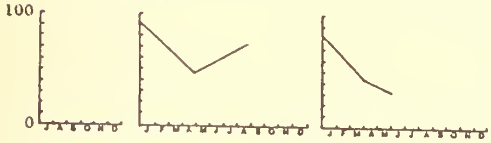
Avian Dominance Index (%) - T-5A, PJSS

94



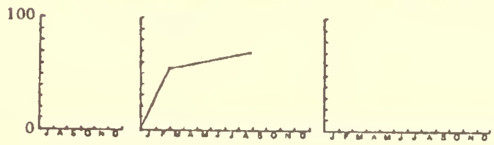
Avian Dominance Index (%) - T-6, CSB

95



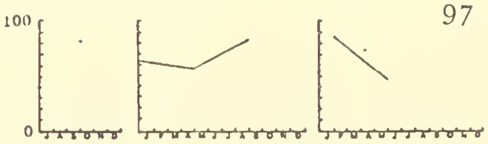
Avian Dominance Index (%) - T-7A, UPSB

96



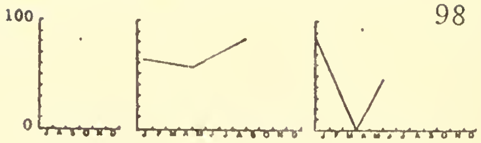
Avian Dominance Index (%) - T-7B, UPTS

97



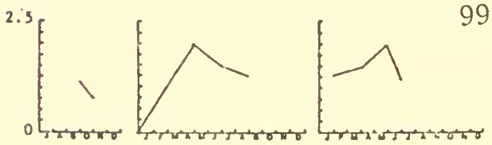
Avian Dominance Index (%) - T-8, MMS

98



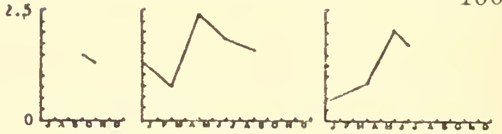
Avian Diversity Index (H') - T-1, CPJR

99



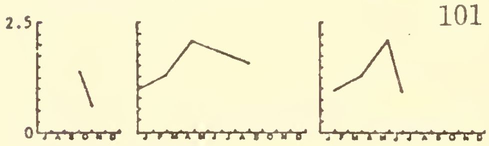
Avian Diversity Index (H') - T-2, RM

100



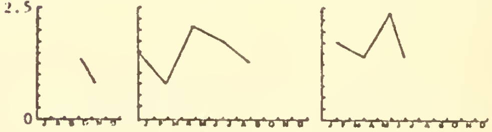
Avian Diversity Index (H') - T-3, BLSB

101



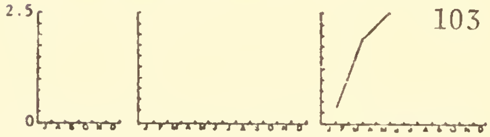
Avian Diversity Index (H') - T-4, PJWD

102



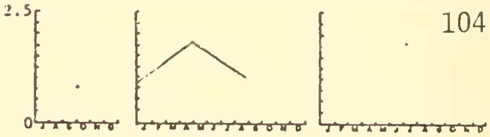
Avian Diversity Index (H') - T-5B, PJWD

103



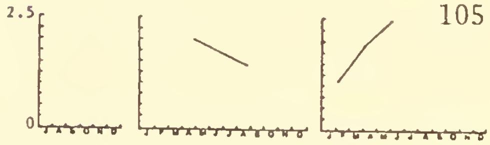
Avian Diversity Index (H') - T-5A, PJSS

104



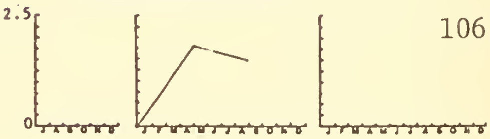
Avian Diversity Index (H') - T-6, CSB

105



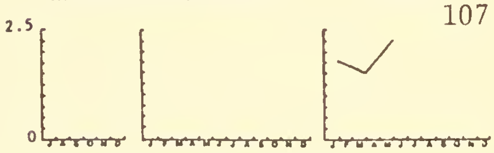
Avian Diversity Index (H') - T-7A, UPSB

106



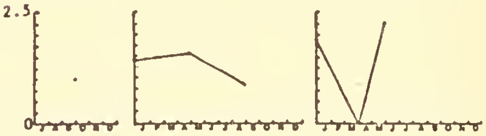
Avian Diversity Index (H') - T-7B, UPTS

107



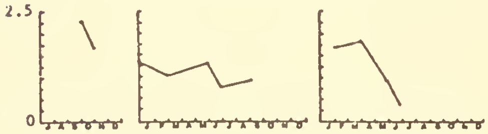
Avian Diversity Index (H') - T-8, MMS

108



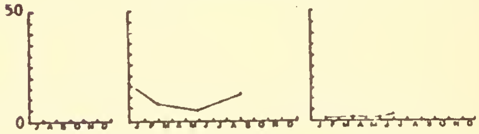
Shorebird and Waterfowl Counts (Total #) -
P-L Ranch Rd.

109



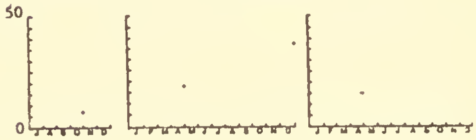
Shorebird and Waterfowl Counts (Total #) -
W. Oldland Ranch Rd.

110



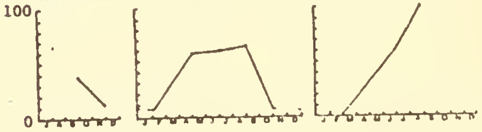
Owls (Total #) Recorded on Tract C-b

111



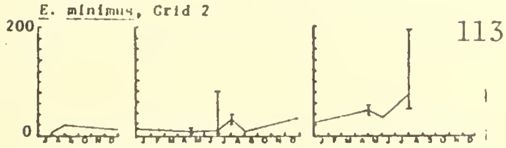
Cottontail Abundance (% frequency) on
Tract C-b

112



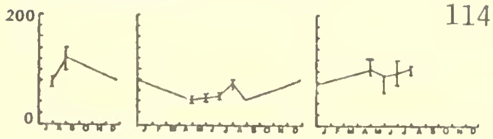
Population Estimates (#) with 95% Conf. Int. for E. minimus, Grid 2

113



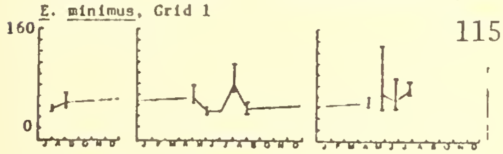
Population Estimates (#) 95% Conf. Int. for P. maniculatus, Grid 2 PJWD

114



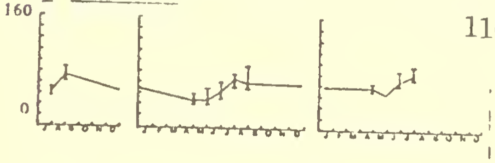
Population Estimates (#) with 95% Conf. Int. for E. minimus, Grid 1

115



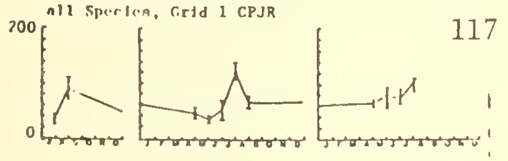
Population Estimates (#) with 95% Conf. Int. for P. maniculatus

116



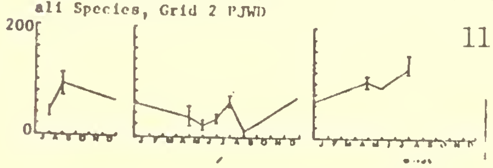
Population Estimate (#) with 95% Conf. Int. for all Species, Grid 1 CPJR

117



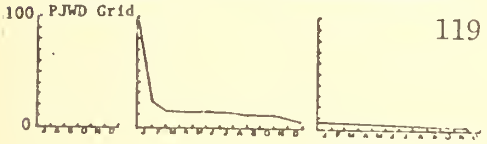
Population Estimates (#) with 95% Conf. Int. for all Species, Grid 2 PJWD

118



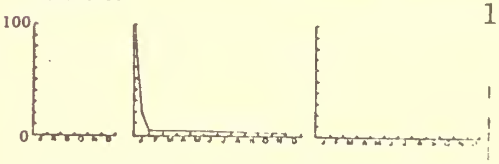
Persistence (%) of Marked Eutamias minimus - PJWD Grid

119



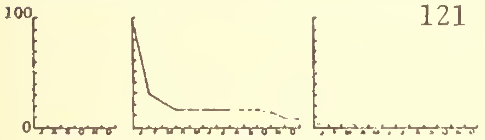
Persistence (%) of marked Peromyscus maniculatus PJWD Grid

120



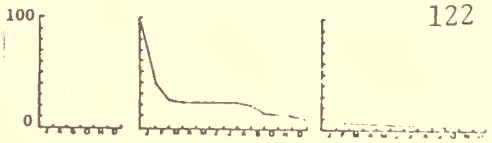
Persistence (%) of marked Eutamias umbrinus PJWD Grid

121



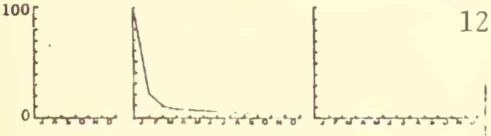
Persistence (%) of Marked Eutamias minimus CPJR Grid

122



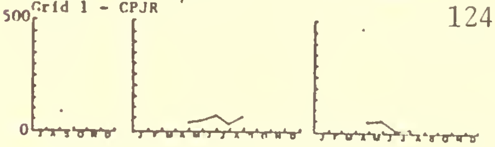
Persistence (%) of marked Peromyscus maniculatus CPJR Grid.

123



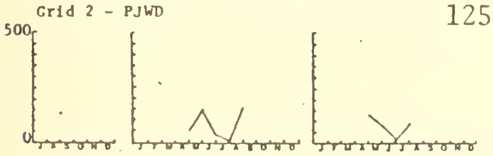
Arthropods (#) Collected from Pit Cans, Grid 1 - CPJR

124



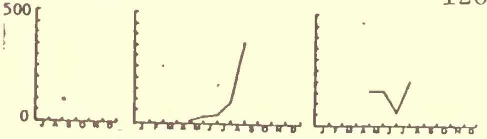
Arthropods (#) Collected from Pit Cans, Grid 2 - PJWD

125



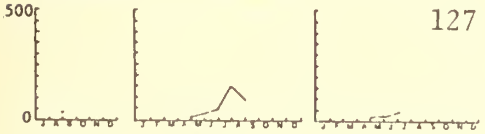
Arthropods (#) Collected from Artemisia tridentata, Grid 1 - CPJR

126



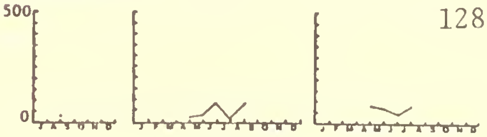
Arthropods (#) Collected from Amelanchier alnifolia, Grid 2 - PJWD

127

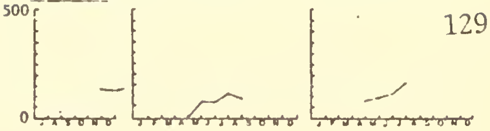


Arthropods (#) Collected from Cercocarpus montanus, Grid 1 - CPJR

128

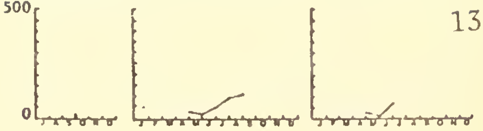


Arthropods (#) Collected from *Cercocarpus montanus*, Grid 2 - PJWD



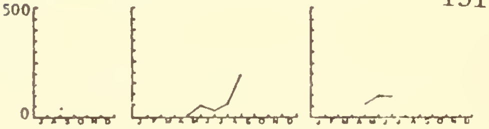
129

Arthropods (#) Collected from *Amelanchier alnifolio*, Grid 1 - CPJR



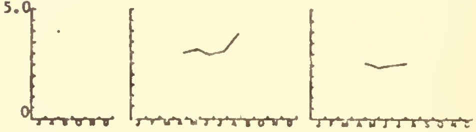
130

Arthropods (#) Collected from *Artemisia tridentata*, Grid 2 - PJWD



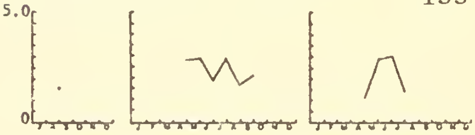
131

Species Diversity (H') of Arthropods Collected in Pit Cans - CPJR



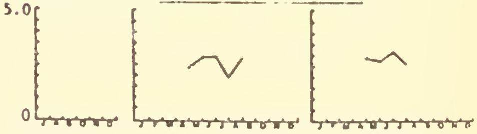
132

Species Diversity (H') of Arthropods Collected in Pit Cans - PJWD



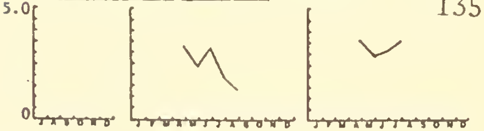
133

Species Diversity (H') of Arthropods Collected in *Amelanchier alnifolio* - CPJR



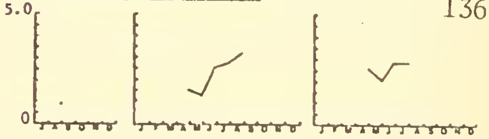
134

Species Diversity (H') of Arthropods Collected in *Amerlanchier alnifolio* - PJWD



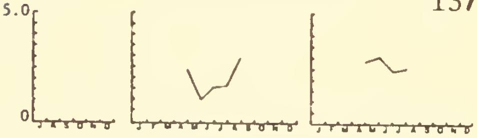
135

Species Diversity (H') of Arthropods Collected in *Cercocarpus montanus* - CPJR



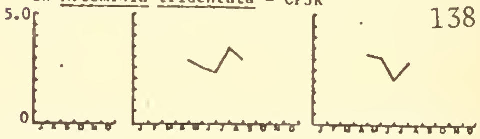
136

Species Diversity (H') of Arthropods Collected in *Cercocarpus montanus* - PJWD



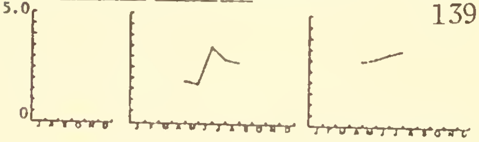
137

Species Diversity (H') of Arthropods Collected in *Artemisia tridentata* - CPJR



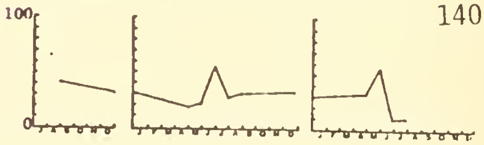
138

Species Diversity (H') of Arthropods Collected in *Artemisia tridentata* - PJWD



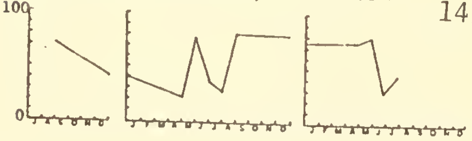
139

Rel. Abundance (#/100PFD) of Arthropods Collected from Pitfalls, Grid 1 - CPJR



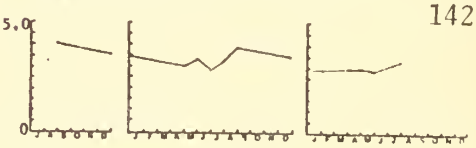
140

Rel. Abundance (#/100PFD) of Arthropods Collected from Pitfalls, Grid 2 - PJWD



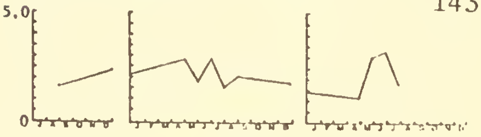
141

Species Diversity (H') of Arthropods Collected from Pitfalls, Grid 1 - CPJR



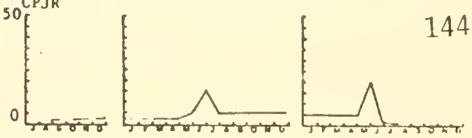
142

Species Diversity (H') of Arthropods Collected from Pitfalls, Grid 2 - PJWD



143

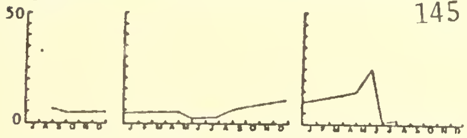
Rel. Abundance (#/100PFD) of Arthropods from Scavenger Trophic Level, Pitfalls on Grid 1 - CPJR



144

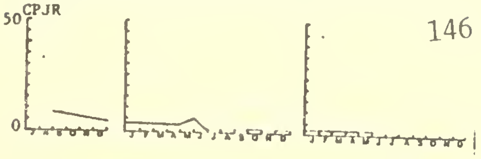
Rel. Abundance (#/100PFD) of Arthropods from Omnivore Trophic Level, Pitfalls of Grid 1 - CPJR

145



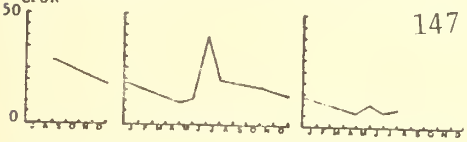
Rel. Abundance (#/100PFD) of Arthropods from Herbivore Trophic Level, Pitfalls of Grid 1 - CPJR

146



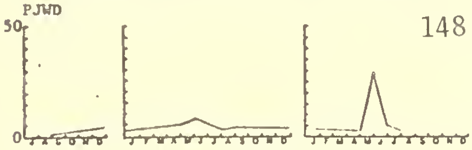
Rel. Abundance (#/100PFD) of Arthropods from Predator Trophic Level, Pitfalls of Grid 1 - CPJR

147



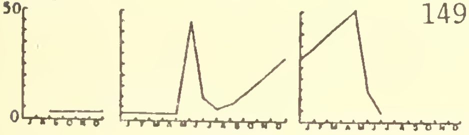
Rel. Abundance (#/100PFD) of Arthropods from Scavenger Trophic Level, Pitfalls of Grid 2 - PJWD

148



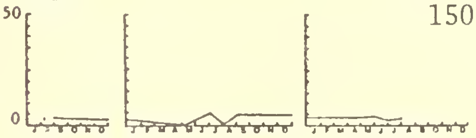
Rel. Abundance (#/100PFD) of Arthropods from Omnivore Trophic Level, Pitfalls of Grid 2 - PJWD

149



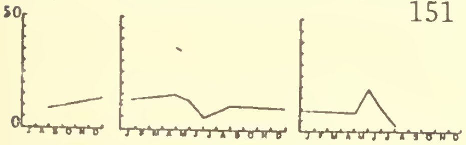
Rel. Abundance (#/100PFD) of Arthropods from Herbivore Trophic Level, Pitfalls of Grid 2 - PJWD

150



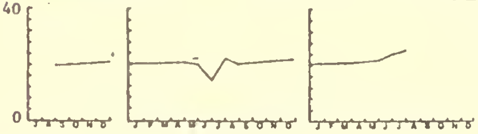
Rel. Abundance (#/100PFD) of Arthropods from Predator Trophic Level, Pitfalls of Grid 2 - PJWD

151



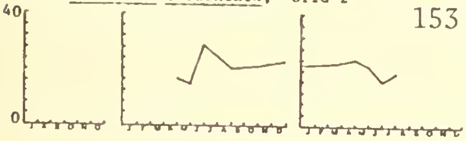
Species Diversity (H') of Arthropods Collected From *Artemisia tridentata*, Grid 1

152



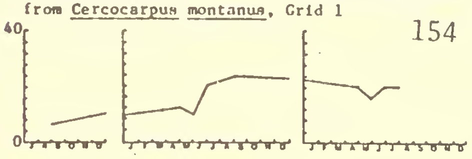
Species Diversity (H') of Arthropods Collected from *Artemisia tridentata*, Grid 2

153



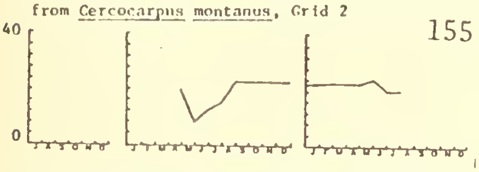
Species Diversity (H') of Arthropods Collected from *Cercocarpus montanus*, Grid 1

154



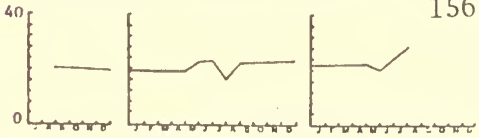
Species Diversity (H') of Arthropods Collected from *Cercocarpus montanus*, Grid 2

155



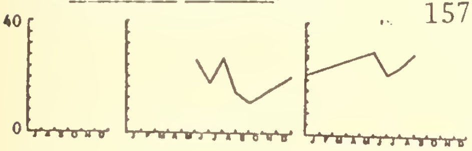
Species Diversity (H') of Arthropods Collected from *Amelanchier alnifolia*, Grid 1

156



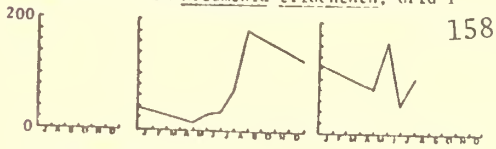
Species Diversity (H') of Arthropods Collected from *Amelanchier alnifolia*, Grid 1

157



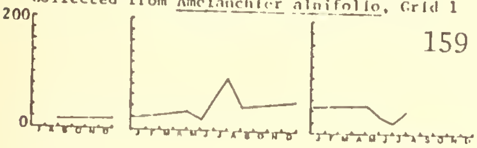
Rel. Abundance (#/100 beats) of Arthropods Collected from *Artemisia tridentata*, Grid 1

158



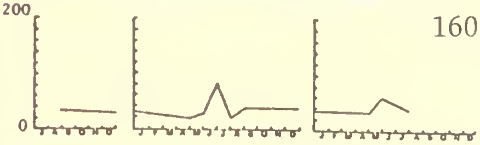
Rel. Abundance (#/100 beats) of Arthropods Collected from *Amelanchier alnifolia*, Grid 1

159

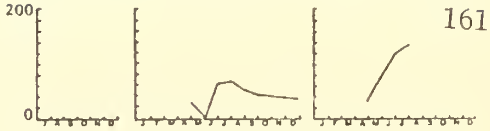


Rel. Abundance (#/100 beats) of Arthropods Collected from *Cercocarpus montanus*, Grid 1

160

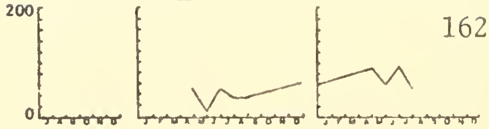


Rel. Abundance (#/100 beats) of Arthropods
Collected from *Cercocarpus montanus*, Grid 2



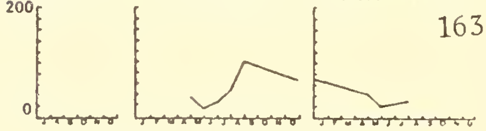
161

Rel. Abundance (#/100 beats) of Arthropods
Collected from *Artemisia tridentata*, Grid 2



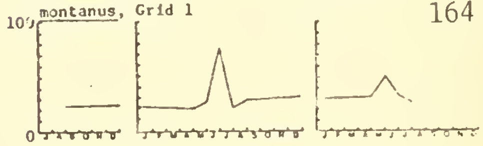
162

Rel. Abundance (#/100 beats) of Arthropods
Collected from *Amelanchier alnifolio*, Grid 2



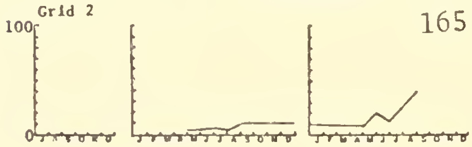
163

Rel. Abundance (#/TL) of Arthropods from
Herbivore Trophic Level, *Cercocarpus*
montanus, Grid 1



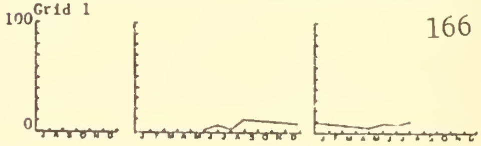
164

Rel. Abundance (#/TL) of Arthropods from
Predator Trophic Level, *Cercocarpus montanus*
Grid 2



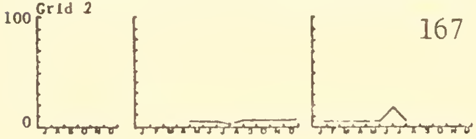
165

Rel. Abundance (#/TL) of Arthropods from
Predator Trophic Level, *Cercocarpus montanus*
Grid 1



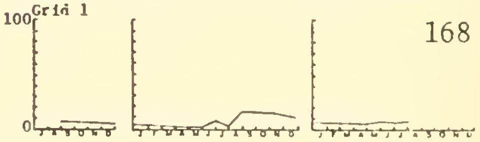
166

Rel. Abundance (#/TL) of Arthropods from
Omnivore Trophic Level, *Cercocarpus montanus*
Grid 2



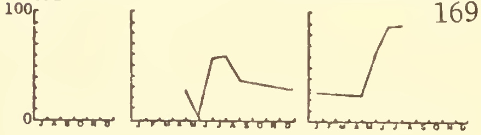
167

Rel. Abundance (#/TL) of Arthropods from
Omnivore Trophic Level, *Cercocarpus montanus*
Grid 1



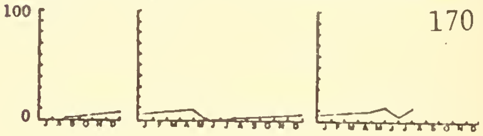
168

Rel. Abundance (#/TL) of Arthropods from
Herbivore Trophic Level, *Cereocarpus montanus*
Grid 2



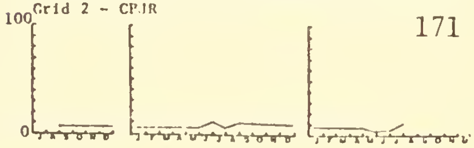
169

Rel. Abundance (#/TL) of Arthropods from
Omnivore Trophic Level, *Amelanchier alnifolio*
Grid 1 - CPJR



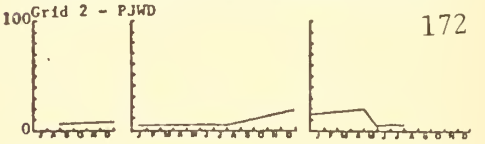
170

Rel. Abundance (#/TL) of Arthropods from
Predator Trophic Level, *Amelanchier alnifolio*
Grid 2 - CPJR



171

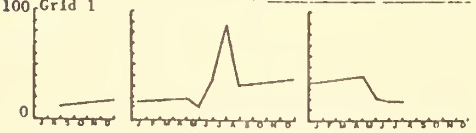
Rel. Abundance (#/TL) of Arthropods from
Predator Trophic Level, *Amelanchier alnifolio*
Grid 2 - PJWD



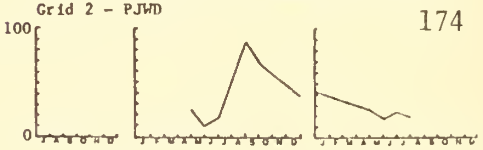
172

173

Rel. Abundance (#/TL) of Arthropods from
Herbivore Trophic Level, *Amelanchier alnifolio*
Grid 1

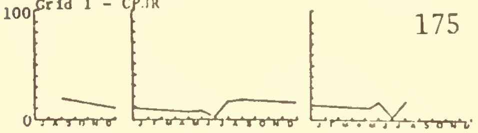


Rel. Abundance (#/TL) of Arthropods from
Herbivore Trophic Level, *Amelanchier alnifolio*
Grid 2 - PJWD



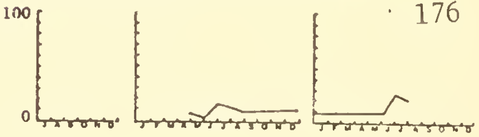
174

Rel. Abundance (#/TL) of Arthropods from
Predator Trophic Level, *Artemisia tridentata*
Grid 1 - CPJR



175

Rel. Abundance (#/TL) of Arthropods from
Predator Trophic Level, Artemisia tridentata
Grid 2 - PJWD



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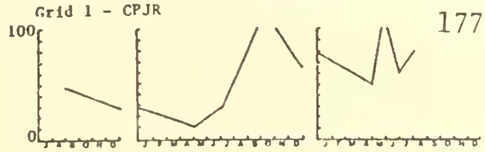
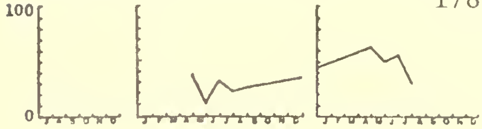
177

Rel. Abundance (#/TL) of Arthropods from Herbivore Trophic Level, *Artemisia tridentata* Grid 1 - CPJR



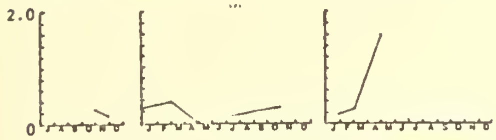
178

Rel. Abundance (#/TL) of Arthropods from Herbivore Trophic Level, *Artemisia tridentata* Grid 2 - PJWD



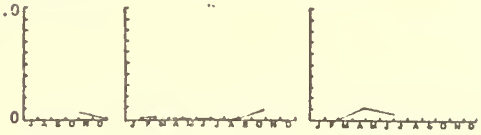
179

Benthic Invert. Biomass (g/sq.ft.) Estimates - Station P3



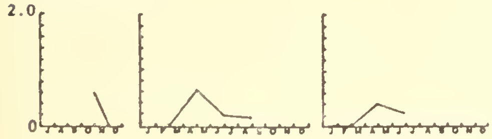
180

Benthic Invert. Biomass (g/sq.ft.) Estimates - Station P6



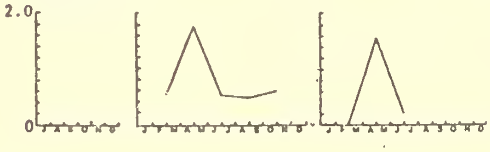
181

Benthic Invert. Biomass (g/sq.ft.) Estimates - Station W3



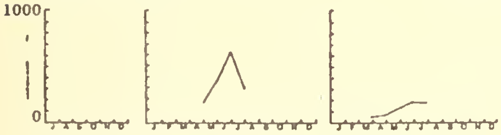
182

Benthic Invert. Biomass (g/sq.ft.) Estimates - Station S1



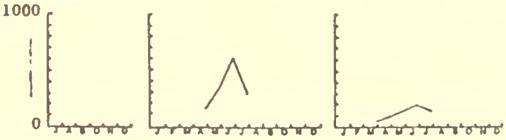
183

Combined Live Standing Crop (kg/ha) Plot 1



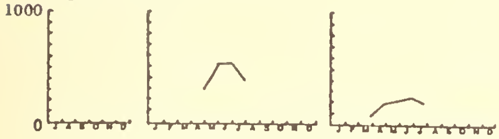
184

Combined Live Standing Crop (kg/ha) Plot 2



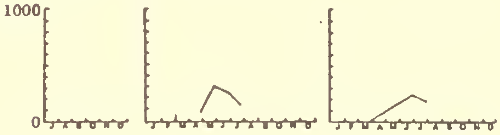
185

Combined Live Standing Crop (kg/ha) Plot 3



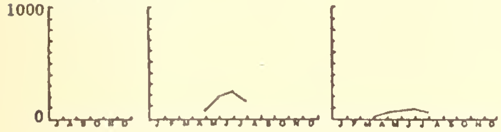
186

Combined Live Standing Crop (kg/ha) Plot 4



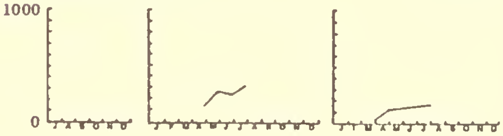
187

Combined Live Standing Crop (kg/ha) Plot 5



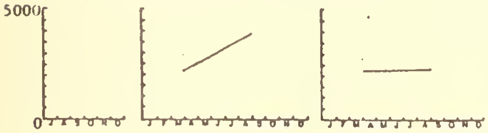
188

Combined Live Standing Crop (kg/ha) Plot 6



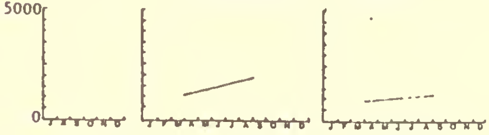
189

Total Shrub Standing Crop (kg/ha) Plot 1



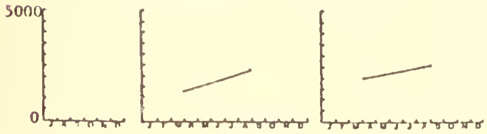
190

Total Shrub Standing Crop (kg/ha) Plot 2

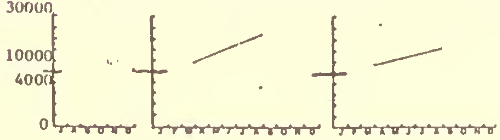


191

Total Shrub Standing Crop (kg/ha) Plot 3

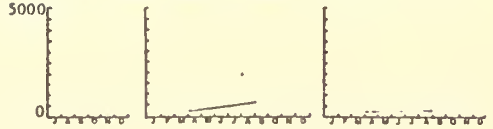


Total Shrub Standing Crop (kg/ha) Plot 4 192



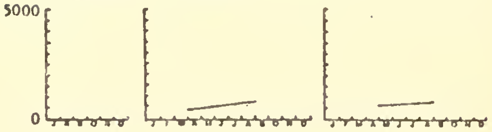
193

Total Shrub Standing Crop (kg/ha) Plot 5



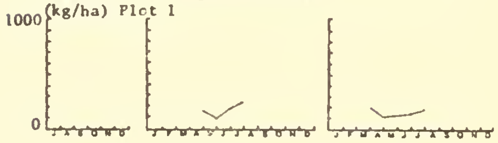
194

Total Shrub Standing Crop (kg/ha) Plot 6



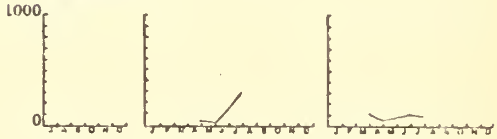
195

Combined Standing Dead Biomass (kg/ha) Plot 1



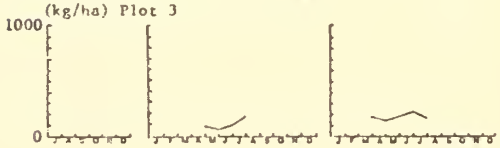
Combined Standing Dead Biomass (kg/ha) Plot 2

196



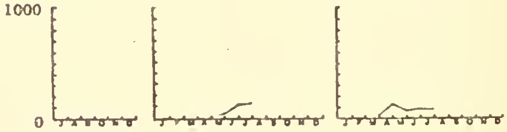
Combined Standing Dead Biomass (kg/ha) Plot 3

197



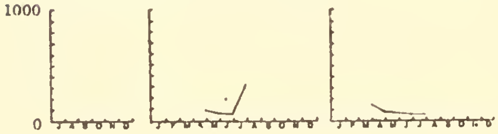
Combined Standing Dead Biomass (kg/ha) Plot 4

198



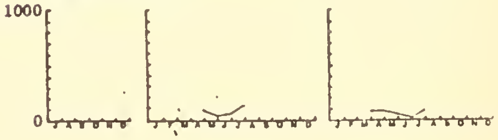
Combined Standing Dead Biomass (kg/ha) Plot 5

199



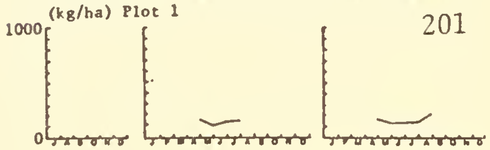
Combined Standing Dead Biomass (kg/ha) Plot 6

200



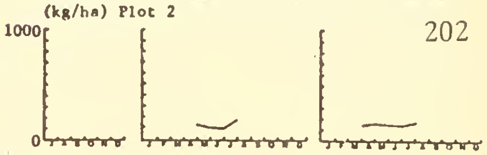
Combined Litter and Prostrate Dead Biomass (kg/ha) Plot 1

201



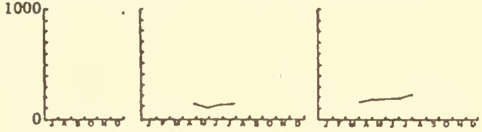
Combined Litter and Prostrate Dead Biomass (kg/ha) Plot 2

202



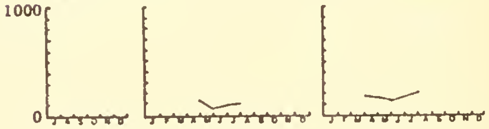
203

Combined Litter and Prostrate Dead Biomass (kg/ha) Plot 3



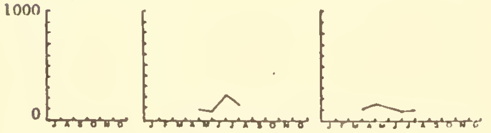
Combined Litter and Prostrate Dead Biomass (kg/ha) Plot 4

204



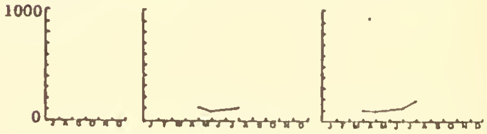
205

Combined Litter and Prostrate Dead Biomass (kg/ha) Plot 5



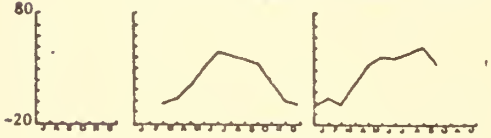
Combined Litter and Prostrate Dead Biomass (kg/ha) Plot 6

206



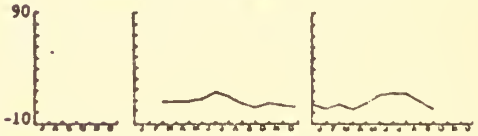
Ground Surface Temp. (°C) - PJWD

207

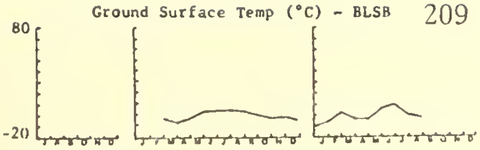


Ground Surface Temp. (°C) - CPJR

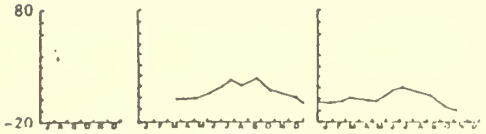
208



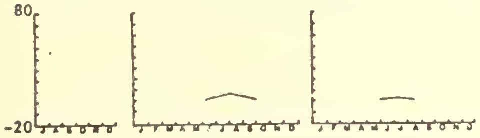
Ground Surface Temp (°C) - BLSB 209



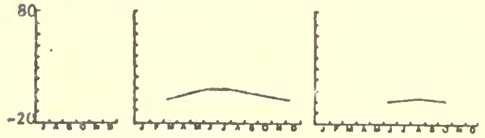
Ground Surface Temp (°C) - UPSB 210



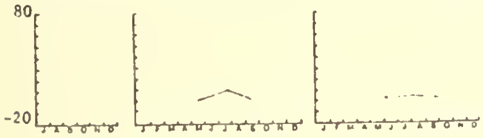
Min. Ground Surface Temp (°C) - BLSB 211



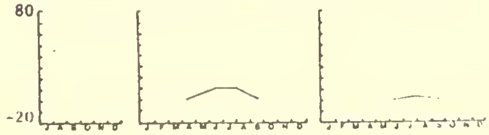
Min. Ground Surface Temp (°C) - UPSB 212



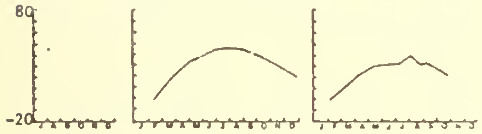
Min. Ground Surface Temp (°C) - PJWD 213



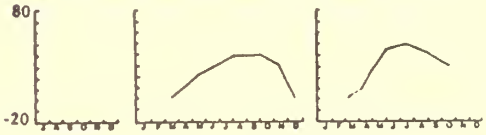
Min. Ground Surface Temp (°C) - CPJR 214



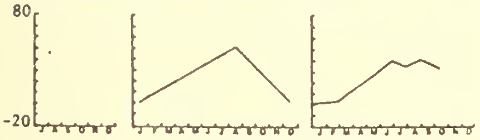
Max.Ground Surface Temp (°C) - BLSB 215



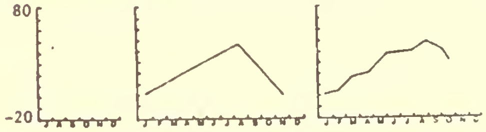
Max. Ground Surface Temp (°C) - UPBS 216



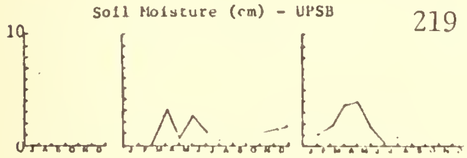
Max. Ground Surface Temp (°C) - PJWD 217



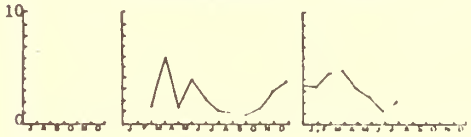
Max. Ground Surface Temp (°C) - CPJR 218



Soil Moisture (cm) - UPSB 219

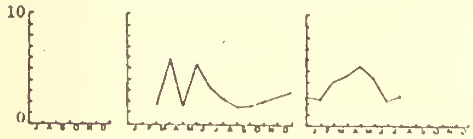


Soil Moisture (cm) - PJWD 220

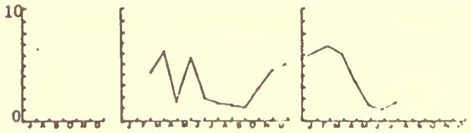


221

Soil Moisture (cm) - BLSB

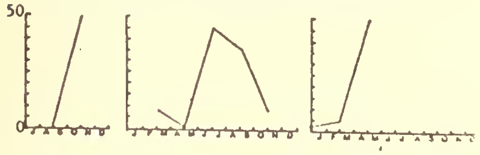


Soil Moisture (cm) - CPJR 222

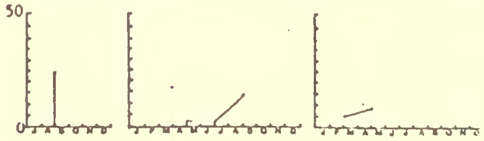


223

No. of Fish (individuals) - Station PJ

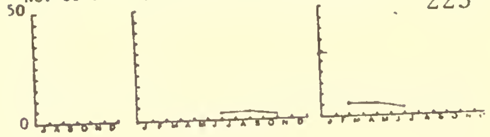


No. of Fish (individuals) - Station Po 224



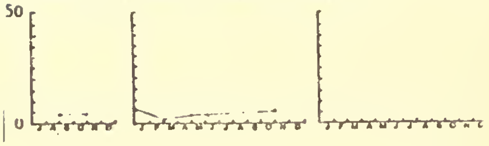
225

No. of Fish (individuals) - Station S1



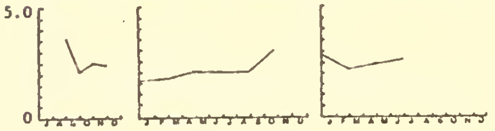
226

No. of Fish (individuals) - Station W3



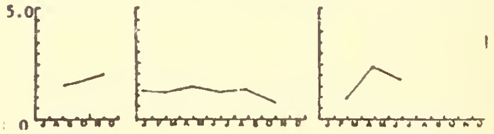
227

Benthic Invert. Sp. Diversity (H') - Station P6



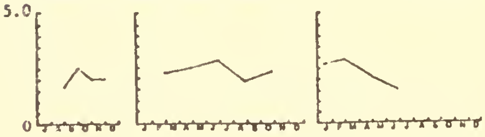
228

Benthic Invert. Sp. Diversity (H') - Station P6



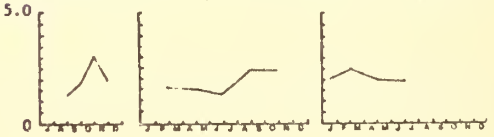
229

Benthic Invert. Sp. Diversity (H') - Station S1



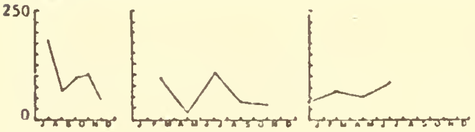
230

Benthic Invert. Sp. Diversity (H') - Station W3



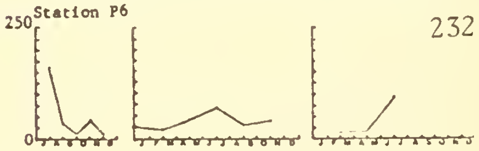
231

No. of Benthic Invertebrates (individuals)
Station P3



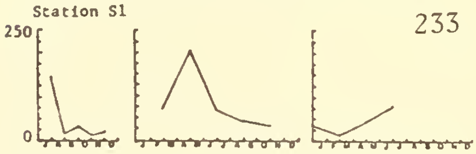
232

No. of Benthic Invertebrates (individuals)
Station P6



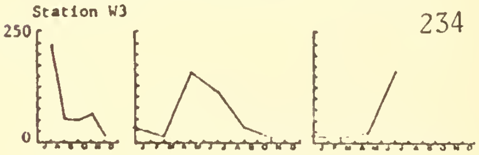
233

No. of Benthic Invertebrates (individuals)
Station S1



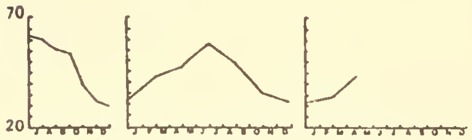
234

No. of Benthic Invertebrates (individuals)
Station W3



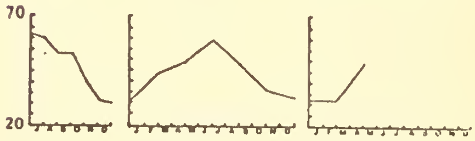
235

Temperature (°F) at Piceance Creek Station
P-1



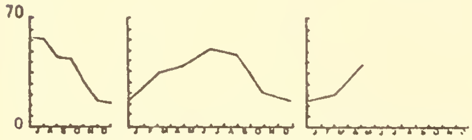
236

Temperature (°F) at Piceance Creek Station
P-2



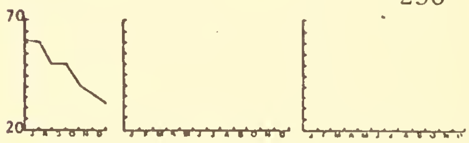
237

Temperature (°F) at Piceance Creek Station
P-3



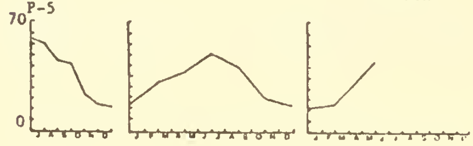
238

Temperature (°F) at Piceance Creek Station
P-4



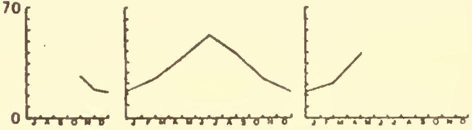
239

Temperature (°F) at Piceance Creek Station
P-5



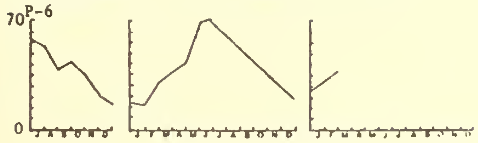
240

Temperature (°F) at Piceance Creek Station
P-5A



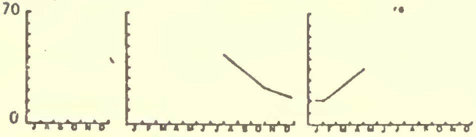
241

Temperature (°F) at Piceance Creek Station P-6



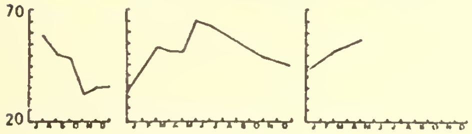
242

Temperature (°F) at Piceance Creek Station P-8, P-7



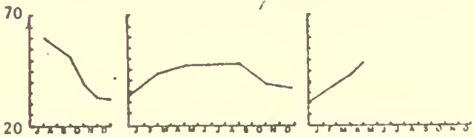
243

Water Temp. (°F) - Stewart Creek Station S-1



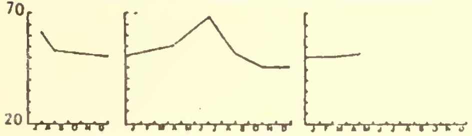
244

Water Temp. (°F) - Stewart Creek Station S-2



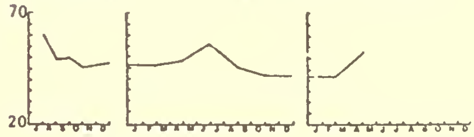
245

Water Temp. (°F) - Stewart Creek Station USL



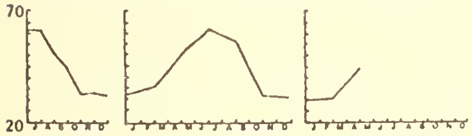
246

Water Temp. (°F) - Stewart Creek Station LSL



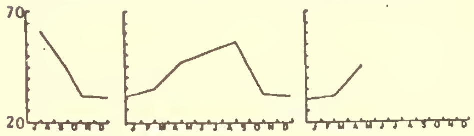
247

Water Temp. (°F) - White River Station WR-1



248

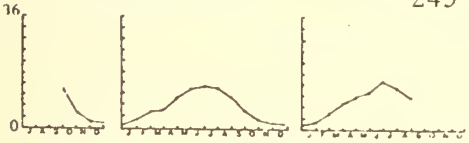
Water Temp. (°F) - White River Station WR-2



269

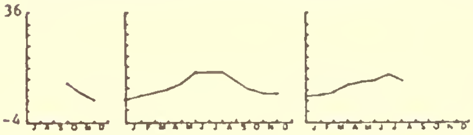
Mean Water Temp. (°C) - Piceance Creek Below Rio Blanco, USGS 09306007

249



Mean Water Temp. (°C) - Stewart Gulch Above Piceance Creek, USGS 09306022

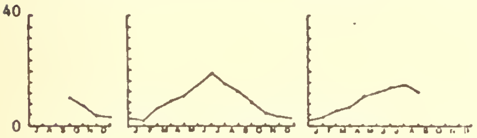
250



2

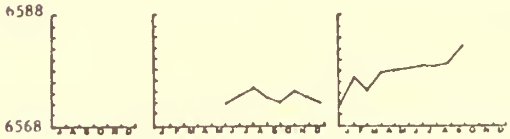
Mean Water Temp. (°C) - Piceance Creek Above Hunter Creek, USGS 09306061

251



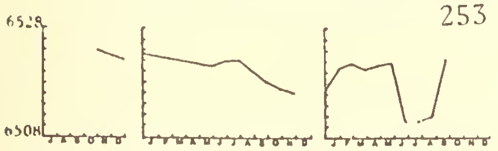
252

Water Levels (ft. msl) - Well SG-10A (GE 6950)



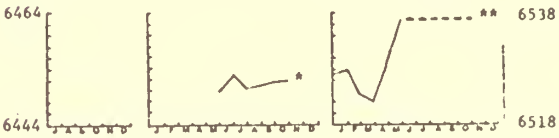
Water Levels (ft. msl) - Well SG-9#2 (GE 6870)

253



Water Levels (ft. msl) - Well SG-8 (GE 6538)

254

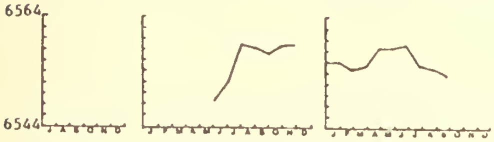


* Well Revoked

** Flowing

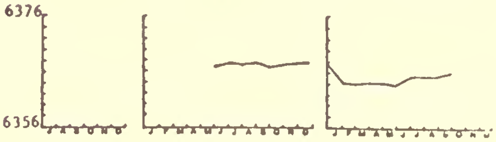
255

Water Levels (ft. msl) - Well SG-6#3 (GE 6888)



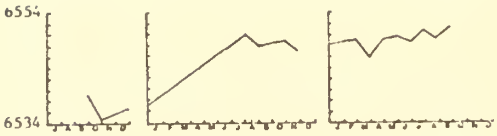
256

Water Levels (ft. msl) - Well SG-1 (GE 6428)



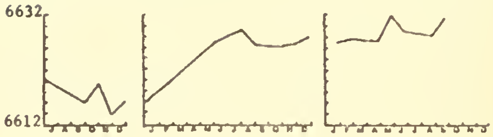
257

Water Levels (ft. msl) - Well AT-1C (GE 6905)



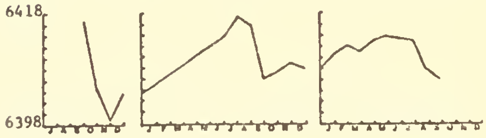
258

Water Levels (ft. msl) - Well Cb-4 (GE 7054)



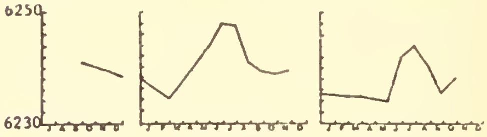
259

Water Levels (ft. msl) - Well Cb-2 (GE 6737)



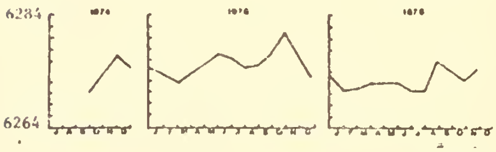
260

Water Levels (ft. msl) - Well A-1 (GE 6279)



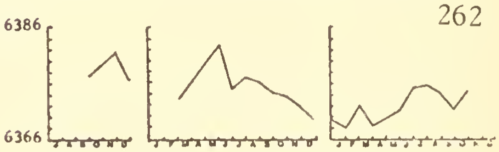
261

Water Levels (ft. msl) - Well A-2 (GE 6281.4)

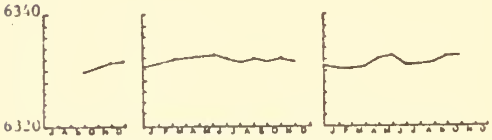


Water Levels (ft. msl) - Well A-3 (GE 6446.6)

262

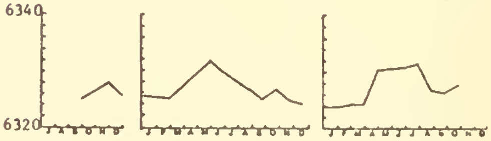


Water Levels (ft. msl) - Well A-5 (6343) 263



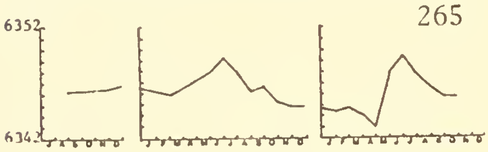
Water Levels (ft. msl) - Well A-6 (GE 6358)

264



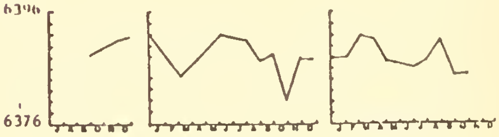
Water Levels (ft. msl) - Well A-7 (GE 6361.0)

265



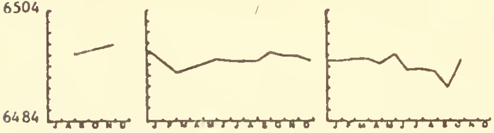
Water Levels (ft. msl) - Well A-8 (GE 6406.4)

266



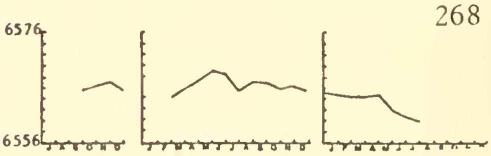
Water Levels (ft. msl) - Well A-9 (GE 6538)

267

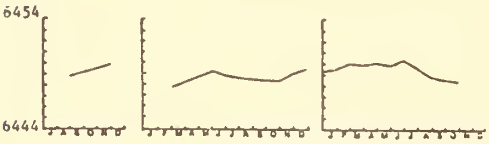


Water Levels (ft. msl) - Well A-10 (GE 6608)

268

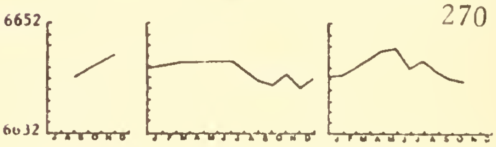


Water Levels (ft. msl) - Well A-11 269
(GE 6502)

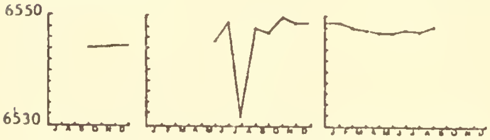


Water Levels (ft. msl) - Well A-12 (GE 6690.3)

270

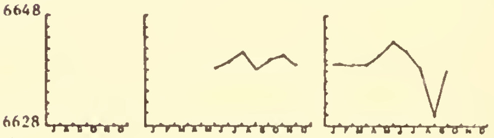


Water Levels (ft. msl) - Well SG-11#3 271
(GE 6900)



272

Water Levels (ft. msl) - Well SG-17#2
(GE 7036)



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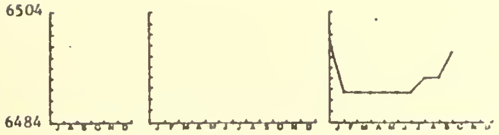
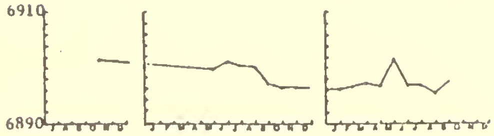
Water Levels (ft. msl) - Well SG-11#1
(GE 6905)



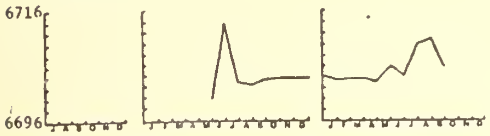
274

Water Levels (ft. msl) - Well SG-18A
(GE 7383)



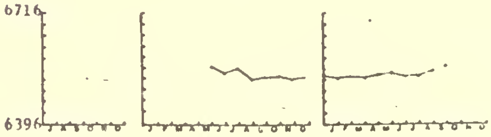
275

Water Levels (ft. msl) - Well SG-21
(GE 6811)



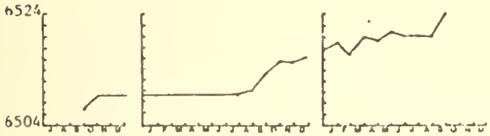
276

Water Levels (ft. msl) - Well Cb-1
(GE 6760)



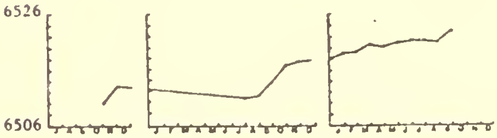
277

Water Levels (ft. msl) - Well AT-1C#1
(GE 6905)



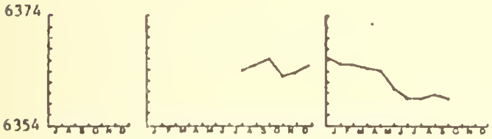
Water Levels (ft. msl) - Well AT-1C#2
(GE 6905)

278



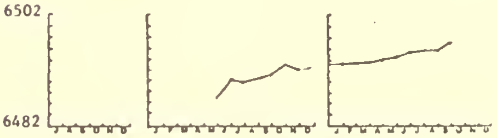
279

Water Levels (ft. msl) - Well SG-1#1
(GE 6428)



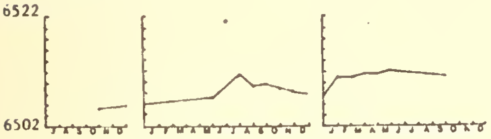
280

Water Levels (ft. msl) - Well SG-8
(GE 6538)



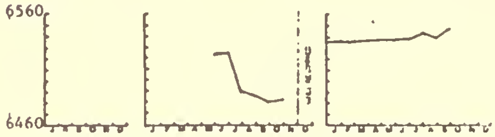
281

Water Levels (ft. msl) - Well SG-9#1
(GE 6870)



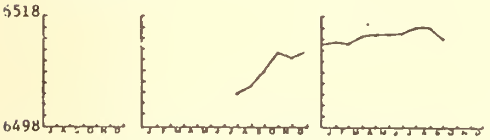
282

Water Levels (ft. msl) - Well SG-10
(GE 6950)



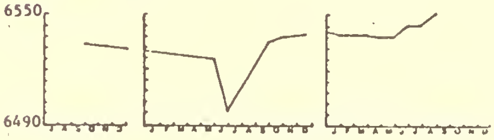
283

Water Levels (ft. msl) - Well SG-6#2
(GE 6888)



284

Water Levels (ft. msl) - Well SG-11#2
(GE 6900)



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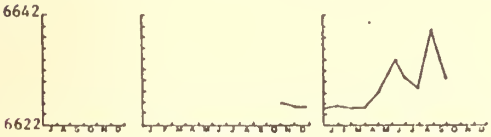
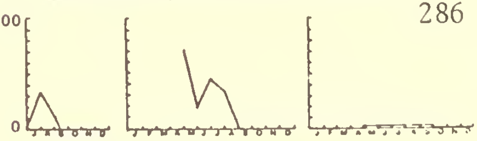
Water Levels (ft. msl) - Well SG-17#1R
(GE 6905)



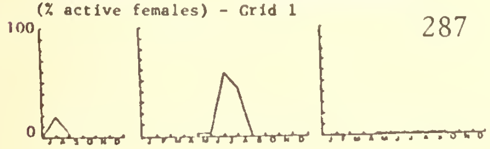
286

Reproductive Activity, Microtus montanus
(% active males) - Grid 1



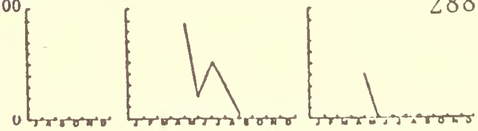
287

Reproductive Activity, Microtus montanus
(% active females) - Grid 1



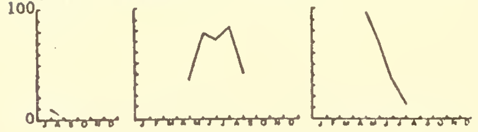
288

Reproductive Activity, Peromyscus maniculatus
(% active males) - Grid 1



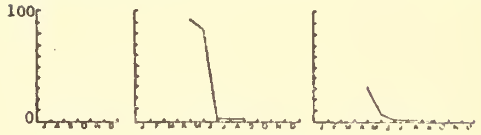
289

Reproductive Activity, Peromyscus maniculatus (% active females) - Grid 1



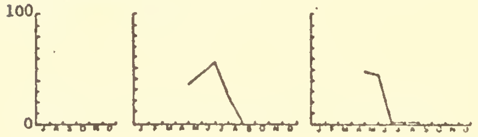
290

Reproductive Activity, Eutamias minimus (% active males) - Grid 1



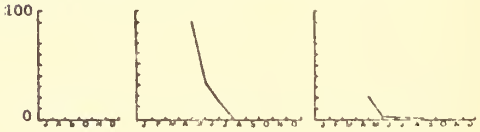
291

Reproductive Activity, Eutamias minimus (% active females) - Grid 1



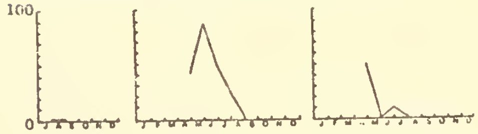
292

Reproductive Activity, Eutamias umbrinus (% active males) - Grid 2



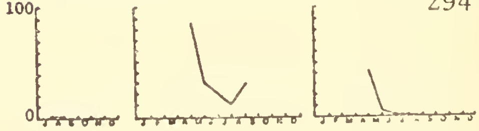
293

Reproductive Activity, Eutamias umbrinus (% active females) - Grid 1



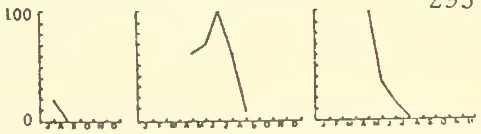
Reproductive Activity, Peromyscus maniculatus (% active males) - Grid 2

294



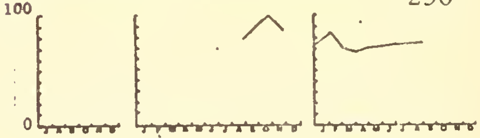
Reproductive Activity, Peromyscus maniculatus (% active females) - Grid 2

295



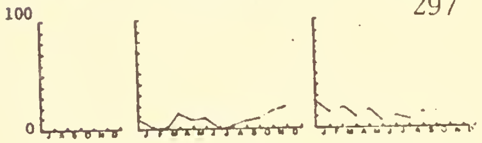
Mean Monthly Visual Range (miles)

296



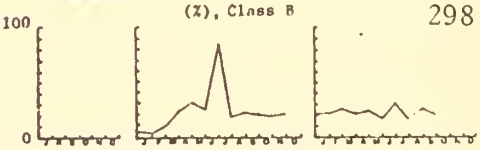
Atmospheric Stability Class Frequency (%),Class A

297



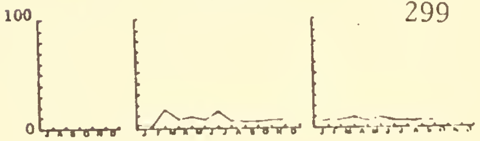
Atmospheric Stability Class Frequency (%), Class B

298



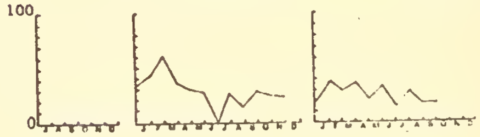
Atmospheric Stability Class Frequency (%), Class C

299



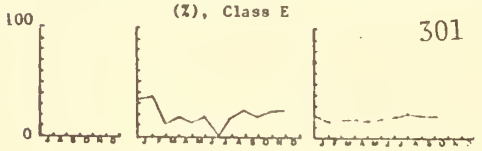
Atmospheric Stability Class Frequency (%), Class D

300



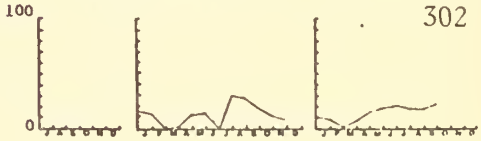
Atmospheric Stability Class Frequency (%), Class E

301



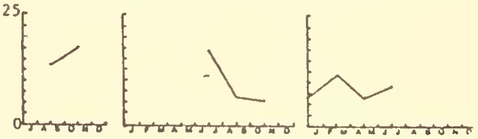
Atmospheric Stability Class Frequency (%), Class F

302



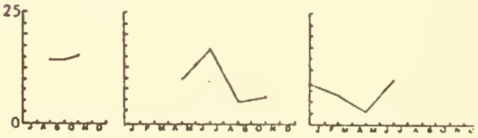
303

No. of Periphyton Species - Station P3



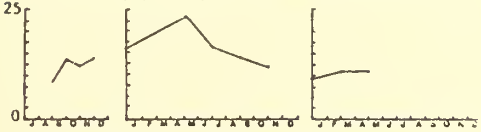
304

No. of Periphyton Species - Station P6



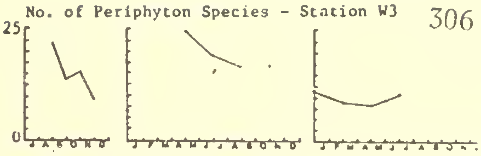
305

No of Periphyton Species - Station S1



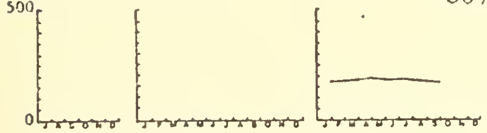
306

No. of Periphyton Species - Station W3



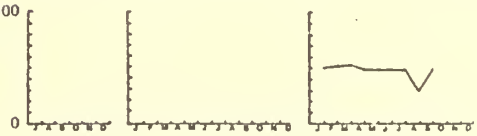
307

Sodium Levels (mg/l) - Alluvial Well A-6



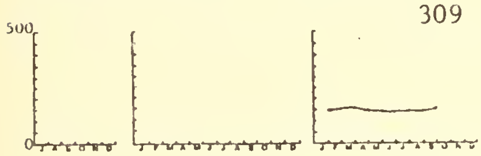
308

Sodium Levels (mg/l) - Alluvial Well A-1



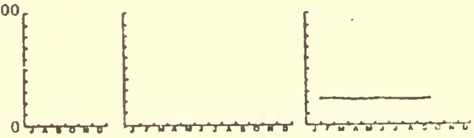
309

Sodium Levels (mg/l) - Alluvial Well A-7



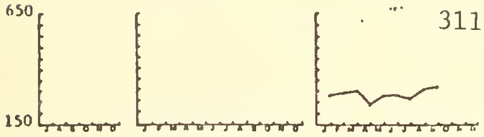
310

Sodium Levels (mg/l) - Alluvial Well A-3



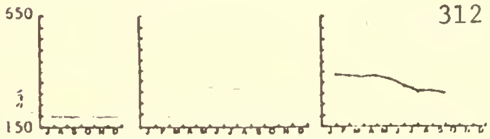
311

Sulfate Levels (mg/l) - Alluvial Well A-7



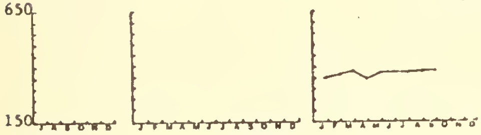
312

Sulfate Levels (mg/l) - Alluvial Well A-6



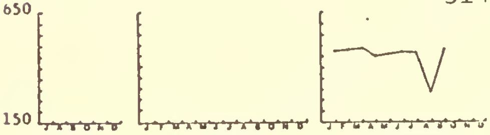
313

Sulfate Levels (mg/l) - Alluvial Well A-3



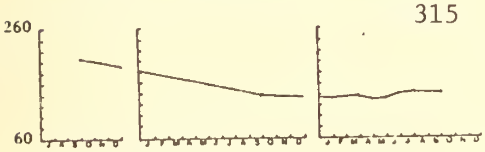
314

Sulfate Levels (mg/l) - Alluvial Well A-1



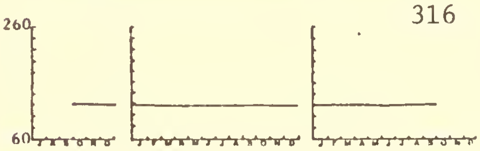
315

Sodium Concentration (mg/l) - Spring S-3



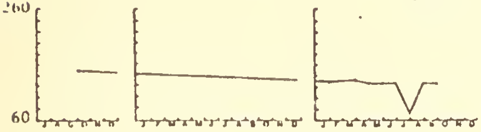
316

Sodium Concentration (mg/l) - Spring S-10



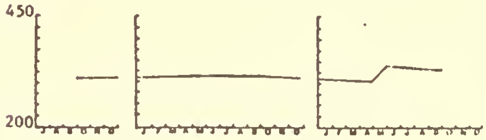
317

Sodium Concentration (mg/l) - Spring S-9



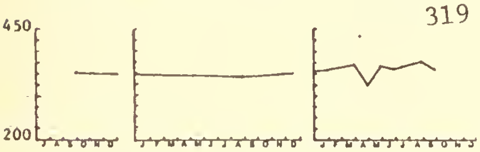
318

Sulfate Concentration (mg/l) - Spring S-10



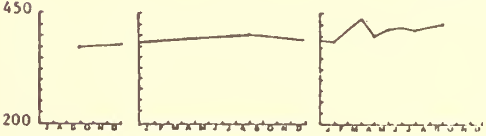
319

Sulfate Concentration (mg/l) - Spring S-9



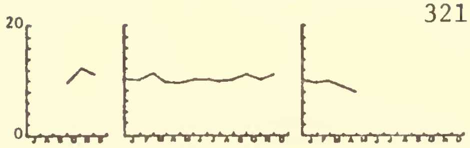
320

Sulfate Concentration (mg/l) - Spring S-3



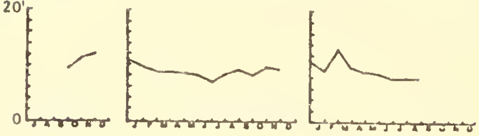
Mean DO (mg/l) - Piceance Creek Below Rio Blanco, USGS 09306007

321



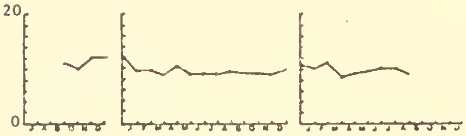
Mean DO (mg/l) - Piceance Creek Above Hunter Creek, USGS 09306061

322



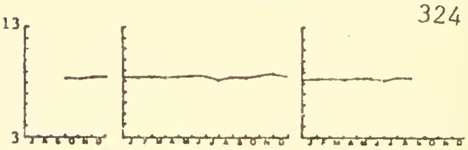
Mean DO (mg/l) - Stewart Gulch Above Piceance Creek, USGS 09306022

323



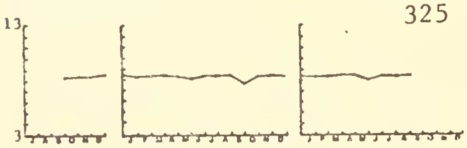
Mean pH - Piceance Creek Below Rio Blanco, USGS 09306007

324



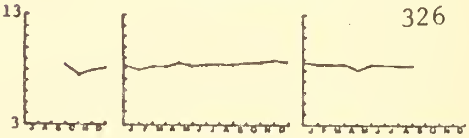
Mean pH - Rio Blanco Above Hunter Creek, USGS 09306061

325



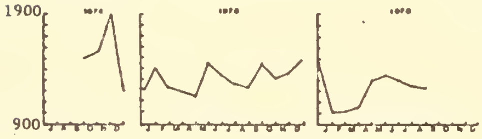
Mean pH - Willow Creek Near Rio Blanco, USGS 09306058

326



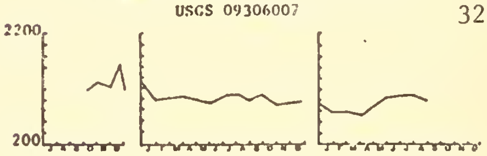
Mean Specific Conductance (micromhos/cm^2) - Piceance Creek Above Hunter Creek, USGS 09306061

327



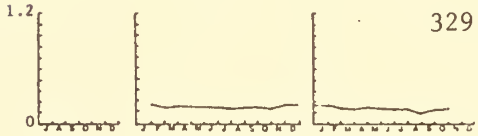
Mean Specific Conductance (micromhos/cm^2) - Piceance Creek Below Rio Blanco, USGS 09306007

328



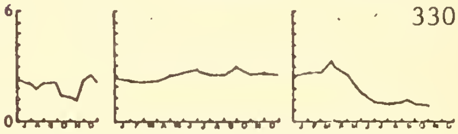
Flow (cfs) - Spring W-2 (S-9), Tract C-b

329



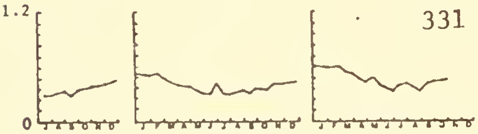
Flow (cfs) - Spring CER-6, Tract C-b

330



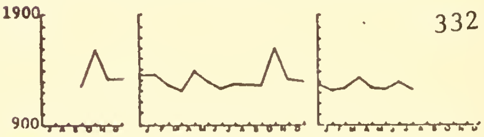
Flow (cfs) - Spring W-3 (S-10), Tract C-b

331



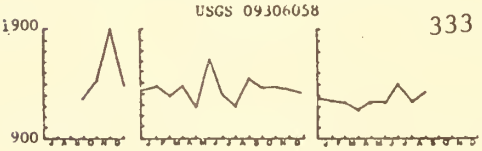
Mean Specific Conductance (micromhos/cm^2) - Stewart Gulch Above West Fork, USGS 09306022

332



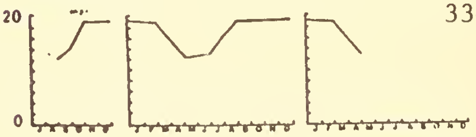
Mean Specific Conductance (micromhos/cm^2) - Willow Creek Near Rio Blanco, USGS 09306058

333



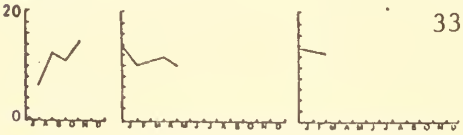
Dissolved Oxygen (mg/l) at Piceance Creek Station P-8, P-7

334



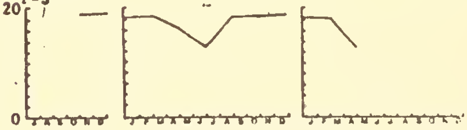
Dissolved Oxygen (mg/l) at Piceance Creek Station P-6

335

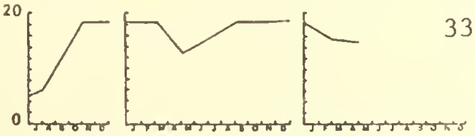


336

Dissolved Oxygen (mg/l) at Piceance Creek Station P-5A

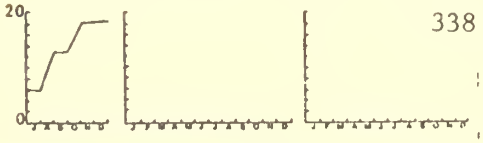


Dissolved Oxygen (mg/l) at Piceance Creek Station P-5



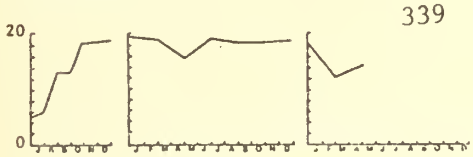
337

Dissolved Oxygen (mg/l) at Piceance Creek Station P-4



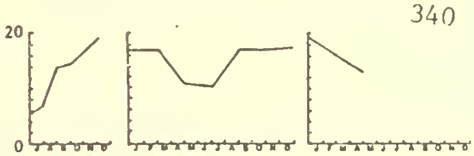
338

Dissolved Oxygen (mg/l) at Piceance Creek Station P-3



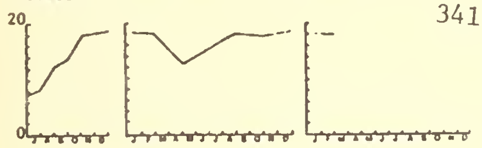
339

Dissolved Oxygen (mg/l) at Piceance Creek Station P-2



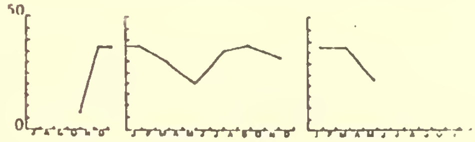
340

Dissolved Oxygen (mg/l) at Piceance Creek Station P-1



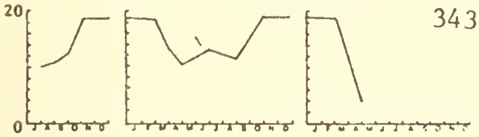
341

DO (mg/l) - Willow Creek Station LWL



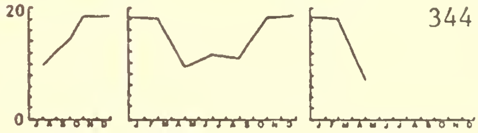
342

DO (mg/l) - White River Station WR-1



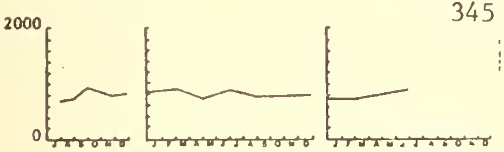
343

DO (mg/l) - White River Station WR-2



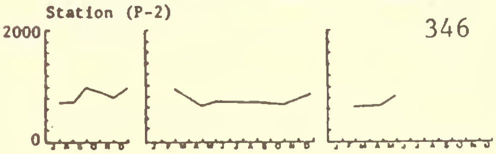
344

Total Dissolved Solids (ppm) at Piceance Creek Station (P-1)



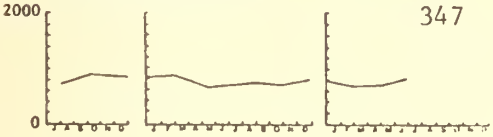
345

Total Dissolved Solids (ppm) at Piceance Creek Station (P-2)



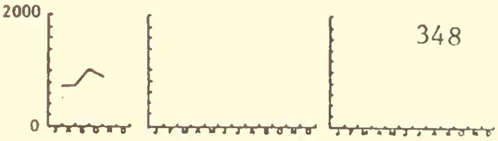
346

Total Dissolved Solids (ppm) at Piceance Creek Station (P-3)



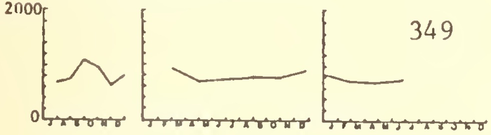
347

Total Dissolved Solids (ppm) at Piceance Creek Station (P-4)



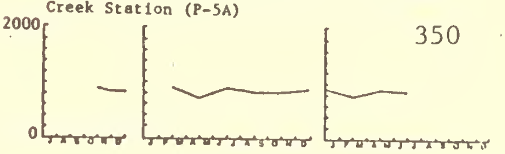
348

Total Dissolved Solids (ppm) at Piceance Creek Station (P-5)



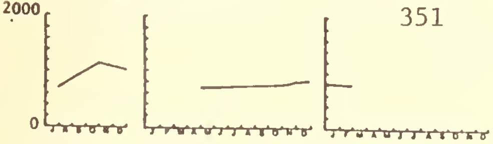
349

Total Dissolved Solids (ppm) at Piceance Creek Station (P-5A)



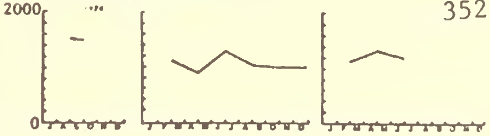
350

Total Dissolved Solids (ppm) at Piceance Creek Station (P-6)



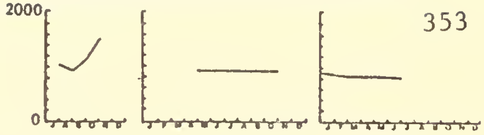
351

Total Dissolved Solids (ppm) at Piceance Creek Station (P-7)



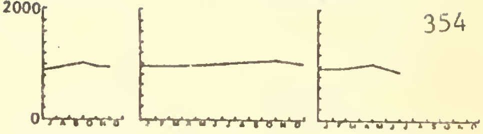
352

TDS (ppm) - Stewart Creek Station S-1



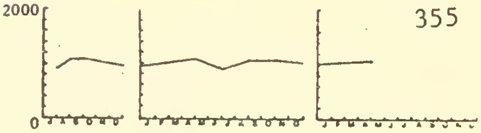
353

TDS (ppm) - Stewart Creek Station S-2



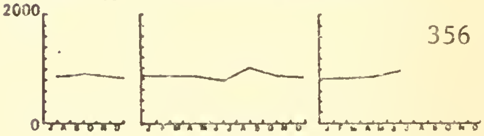
354

TDS (ppm) - Stewart Creek Station USL



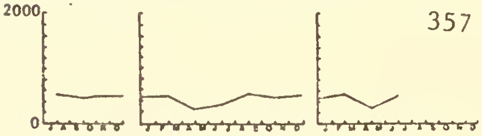
355

TDS (ppm) - Stewart Creek Station LSL



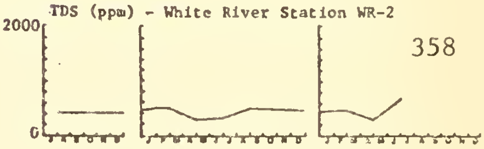
356

TDS (ppm) - White River Station WR-1



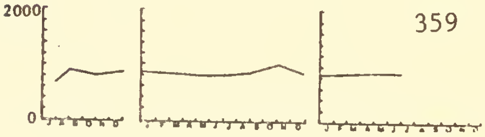
357

TDS (ppm) - White River Station WR-2



358

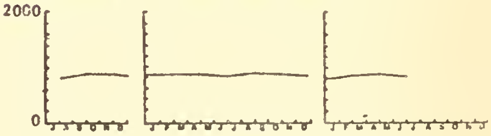
TDS (ppm) - Willow Creek Station W-1



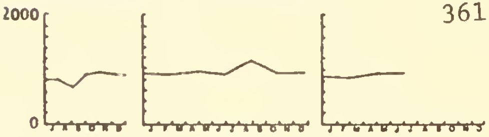
359

360

TDS (ppm) - Willow Creek Station W-2

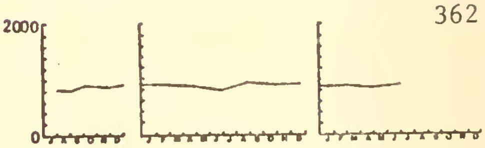


TDS (ppm) - Willow Creek Station W-3



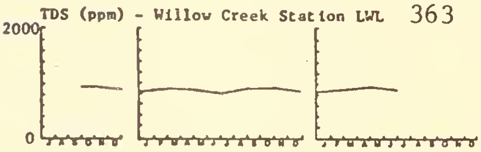
361

TDS (ppm) - Willow Creek Station UWL



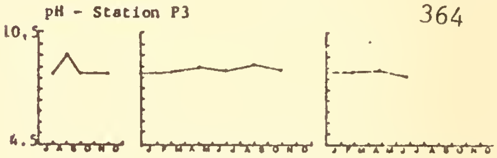
362

TDS (ppm) - Willow Creek Station LWL 363

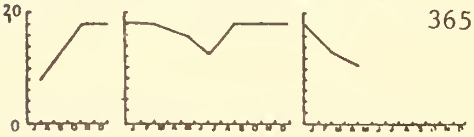


pH - Station P3

364

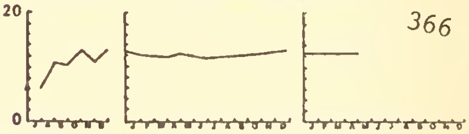


DO (mg/l) - Stewart Creek Station S-2



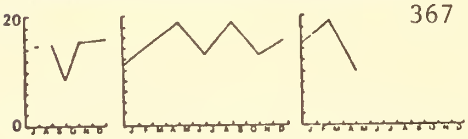
365

DO (mg/l) - Stewart Creek Station S-1



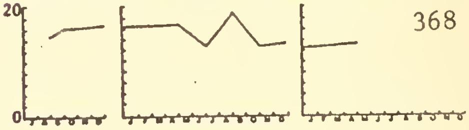
366

DO (mg/l) - Steward Creek Station LSL



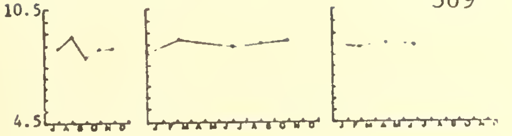
367

DO (mg/l) - Stewart Creek Station USL



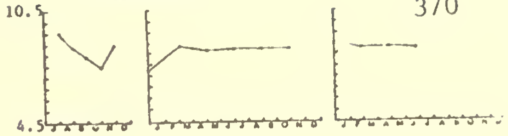
368

pH - Station P6



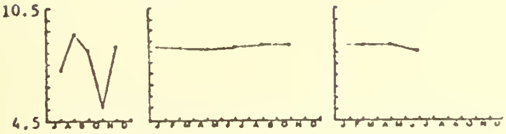
369

pH - Station S1



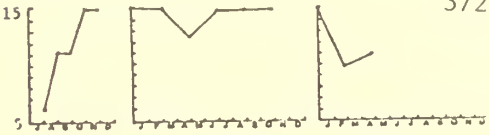
370

pH - Station W3



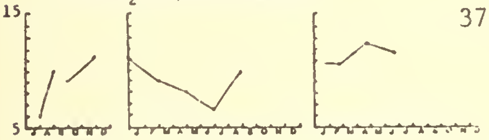
371

Dissolved O_2 (mg/l) - Station P3



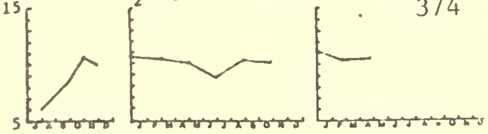
372

Dissolved O_2 (mg/l) - Station P6



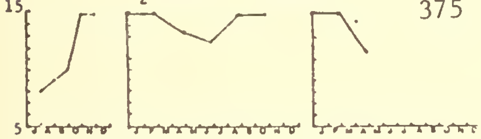
373

Dissolved O_2 (mg/l) - Station S1



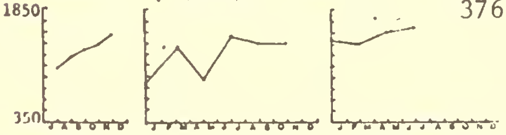
374

Dissolved O_2 (mg/l) - Station W3



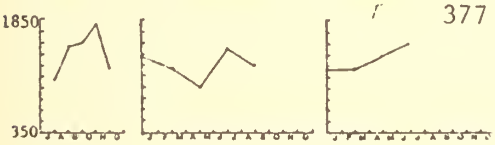
375

Conductivity (µmhos/cm) - Station P6



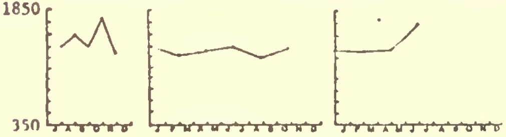
376

Conductivity (µmhos/cm) - Station ~~S1~~



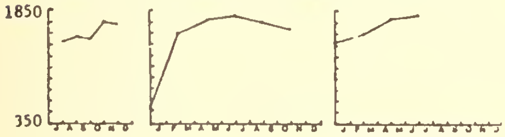
377

Conductivity (µmhos/cm) - Station S1



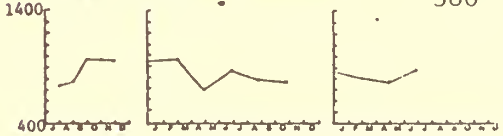
378

Conductivity (µmhos/cm) - Station W3



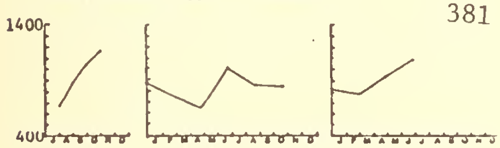
379

Total Solids (ppm) - Station P3



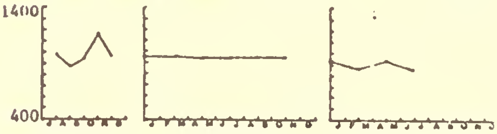
380

Total Solids (ppm) - Station P6



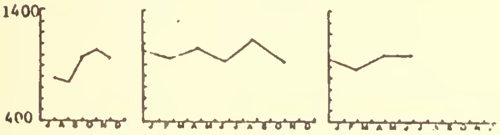
381

Total Solids (ppm) - Station S1



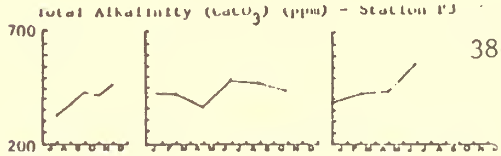
382

Total Solids (ppm) - Station W3



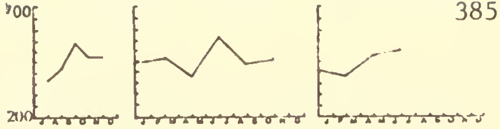
383

Total Alkalinity ($CaCO_3$) (ppm) - Station P3



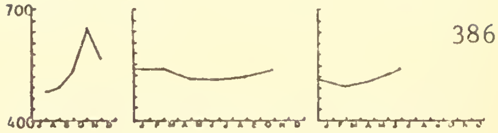
384

Total Alkalinity (CaCO$_3$) (ppm) - Station P6



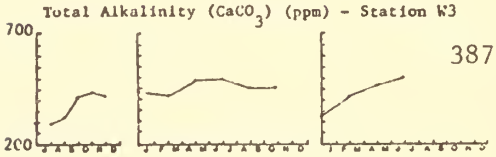
385

Total Alkalinity (CaCO$_3$) (ppm) - Station S1



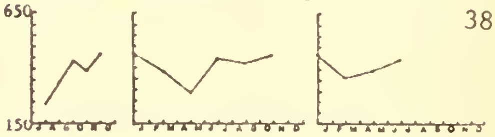
386

Total Alkalinity (CaCO$_3$) (ppm) - Station W3



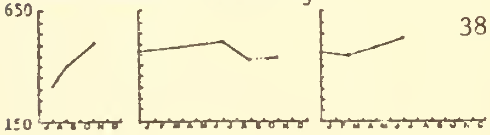
387

Total Hardness (ppm as CaCO$_3$) - Station P3



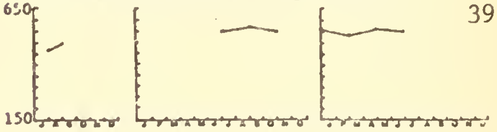
388

Total Hardness (ppm as CaCO$_3$) - Station P6



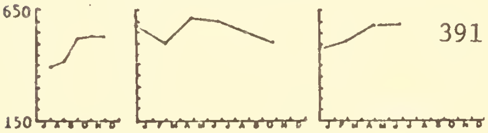
389

Total Hardness (ppm as CaCO$_3$) - Station S1



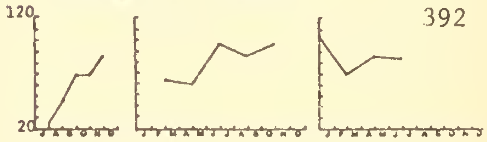
390

Total Hardness (ppm as CaCO$_3$) - Station W3



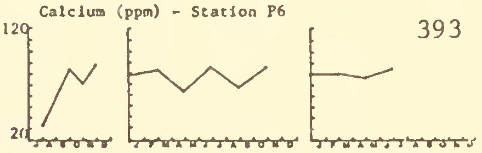
391

Calcium (ppm) - Station P3



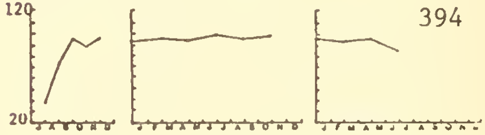
392

Calcium (ppm) - Station P6



393

Calcium (ppm) - Station S1



394

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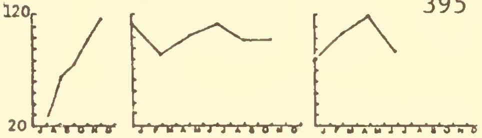
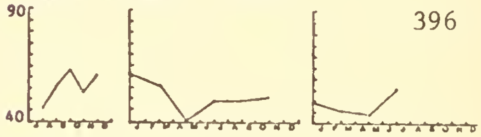


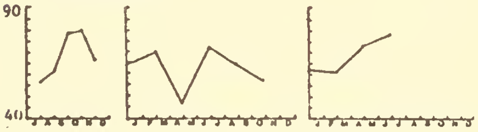
395

Magnesium (ppm) - Station P3



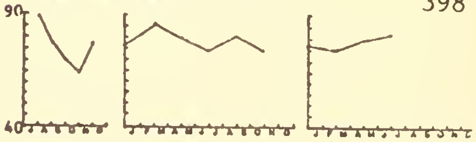
396

Magnesium (ppm) - Station P6



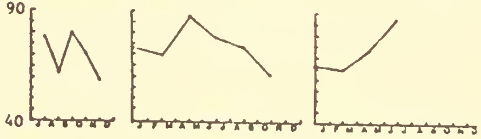
397

Magnesium (ppm) - Station S1



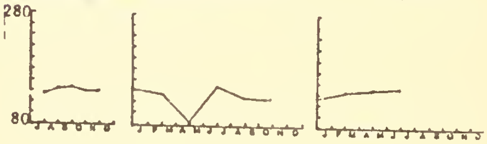
398

Magnesium (ppm) - Station W3



399

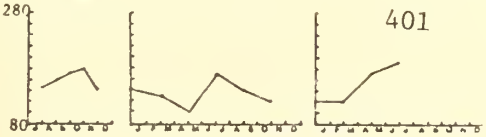
Sodium (ppm) - Station P3



400

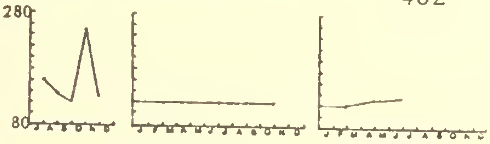
Sodium (ppm) - Station P6

401



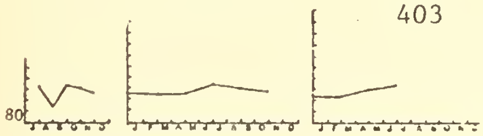
Sodium (ppm) - Station S1

402



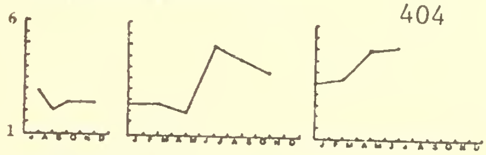
- Station W3

403



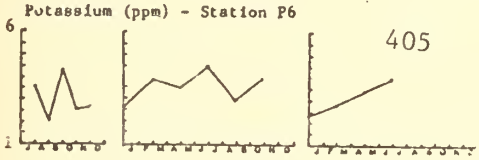
Potassium (ppm) - Station P3

404



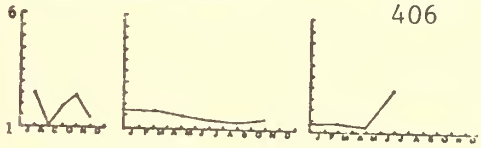
Potassium (ppm) - Station P6

405



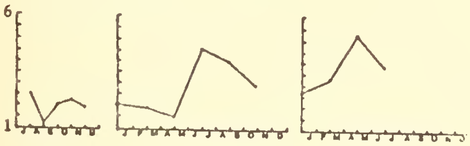
Potassium (ppm) - Station S1

406



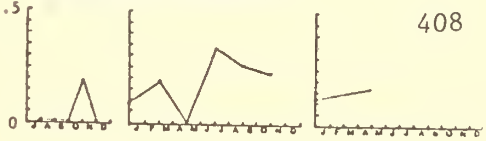
Potassium (ppm) - Station W3

407



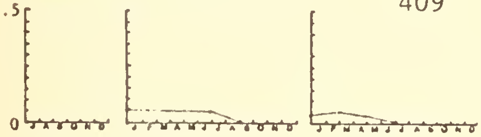
Ammonia (ppm) - Station P3

408



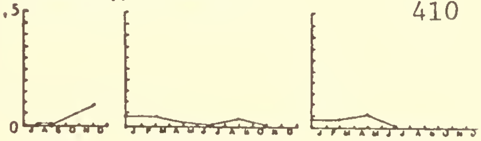
Ammonia (ppm) - Station P6

409



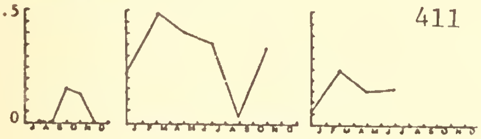
Ammonia (ppm) - Station S1

410



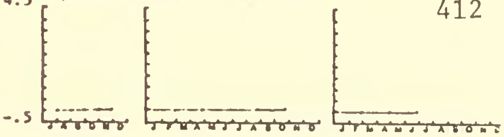
Ammonia (ppm) - Station W3

411



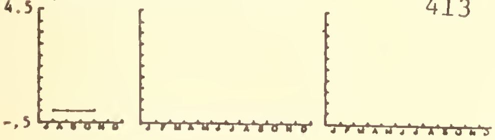
Hydroxide (ppm) - Station P3

412



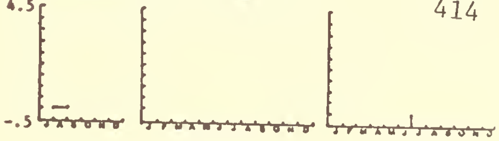
Hydroxide (ppm) - Station P6

413



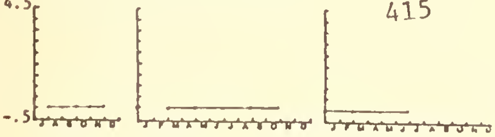
Hydroxide (ppm) - Station S1

414



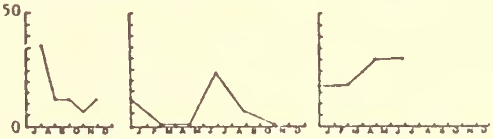
Hydroxide (ppm) - Station W3

415



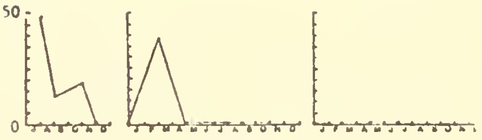
Carbonate (ppm) - Station P3

416



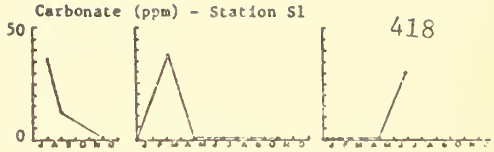
Carbonate (ppm) - Station P6

417



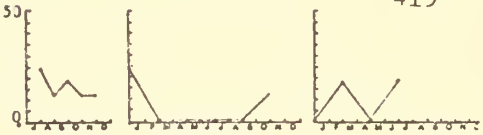
Carbonate (ppm) - Station S1

418



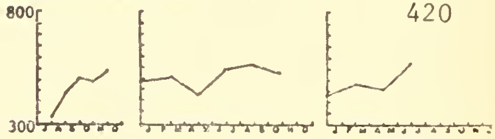
Carbonate (ppm) - Station W3

419



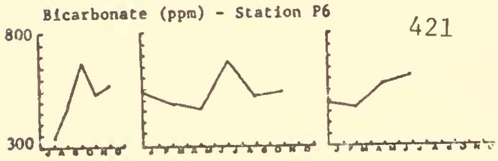
Bicarbonate (ppm) - Station P3

420



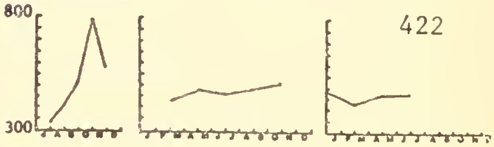
Bicarbonate (ppm) - Station P6

421



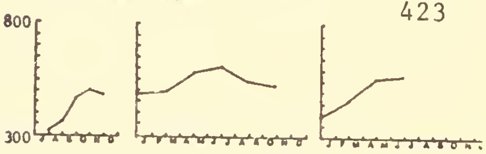
Bicarbonate (ppm) - Station S1

422



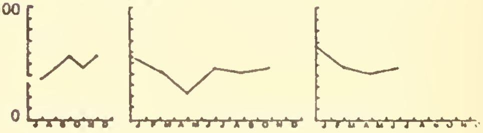
Bicarbonate (ppm) - Station W3

423



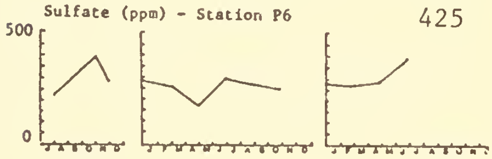
Sulfate (ppm) - Station P3

424



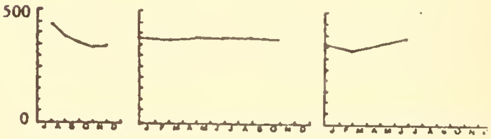
Sulfate (ppm) - Station P6

425



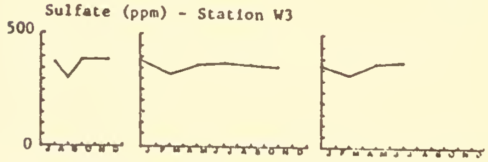
Sulfate (ppm) - Station S1

426



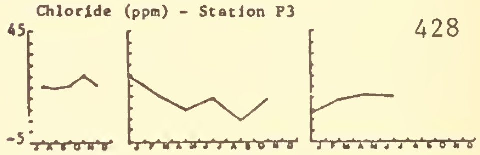
427

Sulfate (ppm) - Station W3



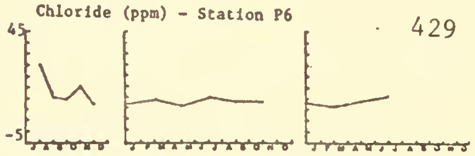
Chloride (ppm) - Station P3

428



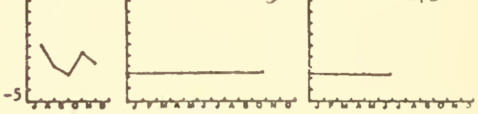
Chloride (ppm) - Station P6

429



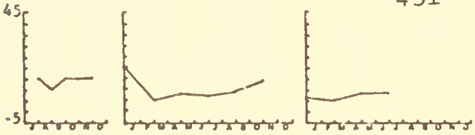
Chloride (ppm) - Station ~~S1~~ S2

430



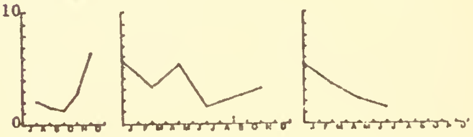
Chloride (ppm) - Station W3

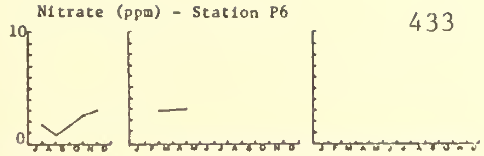
431



Nitrate (ppm) - Station P3

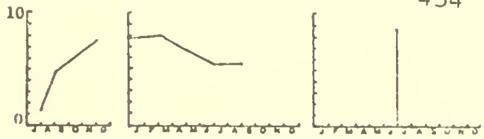
432





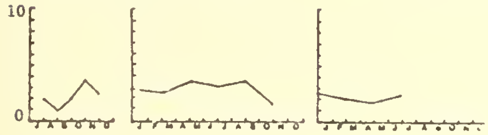
Nitrate (ppm) - Station P6

433



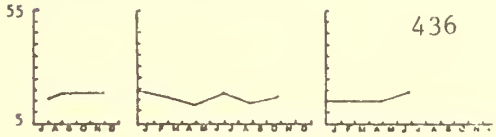
Nitrate (ppm) - Station S1

434



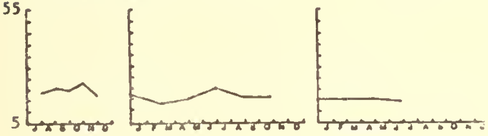
Nitrate (ppm) - Station W3

435



Silica (ppm) - Station P3

436



Silica (ppm) - Station P6

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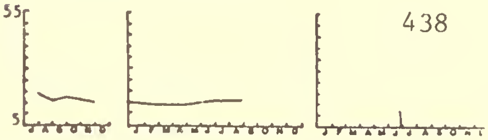
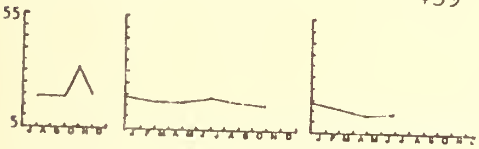


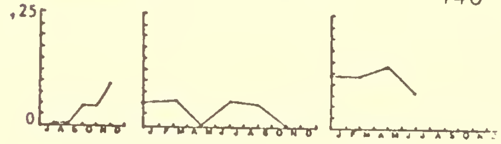
Silica (ppm) - Station S1

438



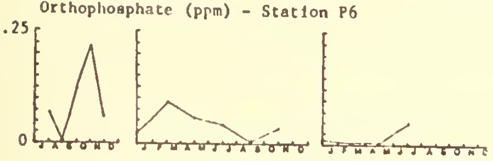
Silica (ppm) - Station W3

439



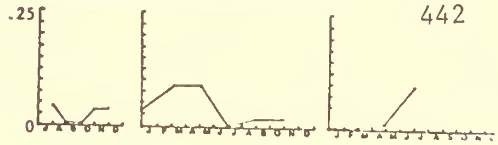
Orthophosphate (ppm) - Station P3

440



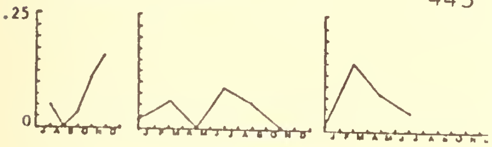
Orthophosphate (ppm) - Station P6

441



Orthophosphate (ppm) - Station S1

442



Orthophosphate (ppm) - Station W3

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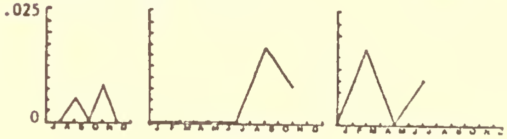
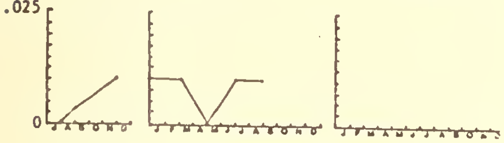


Nitrite (ppm) - Station P3

444



Nitrite (ppm) - Station P6

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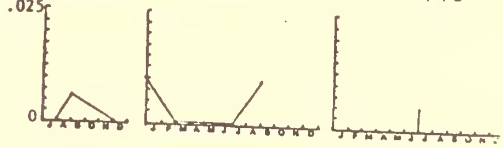
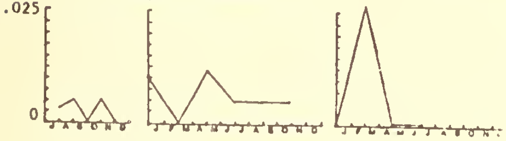


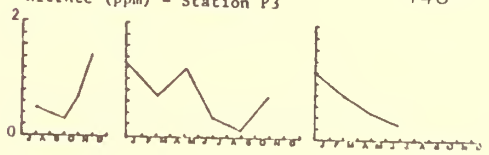
Nitrite (ppm) - Station S1

446



Nitrite (ppm) - Station W3

447

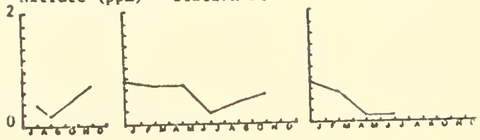


Nitrate (ppm) - Station P3

448

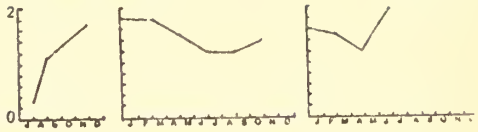
449

Nitrate (ppm) - Station P6



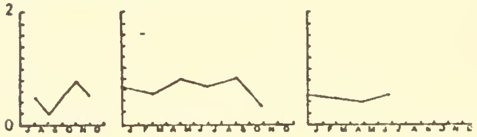
450

Nitrate (ppm) - Station S1



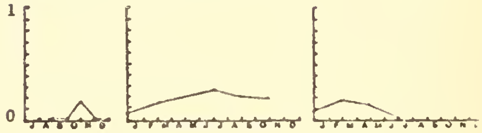
451

Nitrate (ppm) - Station W3



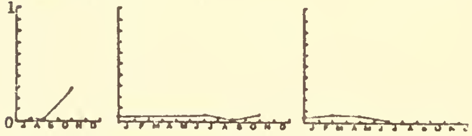
452

Ammonia (ppm) - Station P3



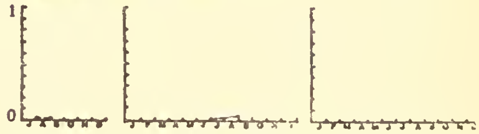
453

Ammonia (ppm) - Station P6



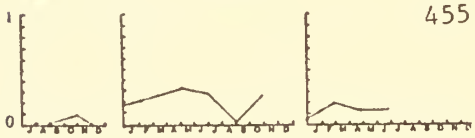
454

Ammonia (ppm) - Station S1



Ammonia (ppm) - Station W3

455



APPENDIX C

APPENDIX C DEVELOPMENT OF THE SUBSYSTEM NETWORKS WITHIN THE TRACT C-b ENVIRONMENTAL SYSTEM

C.1 Introduction

This appendix documents some of the intermediate steps used in developing the total system flow diagram (Figure 5-6). A simplified conceptual view of how major flows and structural units within the C-b system might be visualized is presented in Figure C-1, which is the same as Figure 5-1. In this figure, the system boundary encloses six habitat types, five terrestrial and one aquatic. These are represented by the major columns in the figure. External factors affecting these habitat types are the driving variables of precipitation, temperature, wind, solar radiation, and oil shale development rate. The six habitat types are divided into four subsystem flows -- carbon, heat, water, and land area. These represent the major rows in the figure. The system is "open" with respect to flows of carbon, heat, and water; thus there are sources and sinks of these currencies. The system is "closed" with respect to land area, as land area can neither be increased nor decreased, but must remain constant. Thus there is no source or sink for land area.

C.2 The Initial Conceptualization

In the initial conceptualization in Figure C-1, the major classes of processes accounting for the flows of carbon into the plant-animal subsystem are photosynthesis and immigration. The submodel structure shows a "carbon allocator" which conceptually accounts for transferring animals among habitat types and into and out of the system. The carbon allocator also accounts conceptually for the allocation of plant carbon to animals as feeding flows. There are a relatively large number of feeding flows as each of the animals might feed on each of the plants. These are identified in a food web matrix (Figure 3-4).

In the simplified conception of the system in Figure C-1 the heat flows into the system by radiation and convection and out by conduction. Water flows into the system via precipitation and runin, and it leaves the system via evapotranspiration and runoff. Streamflow is only one type of runoff. The water flows also require an allocator to move water, either as snow or as liquid water, from one habitat type to another above ground and via

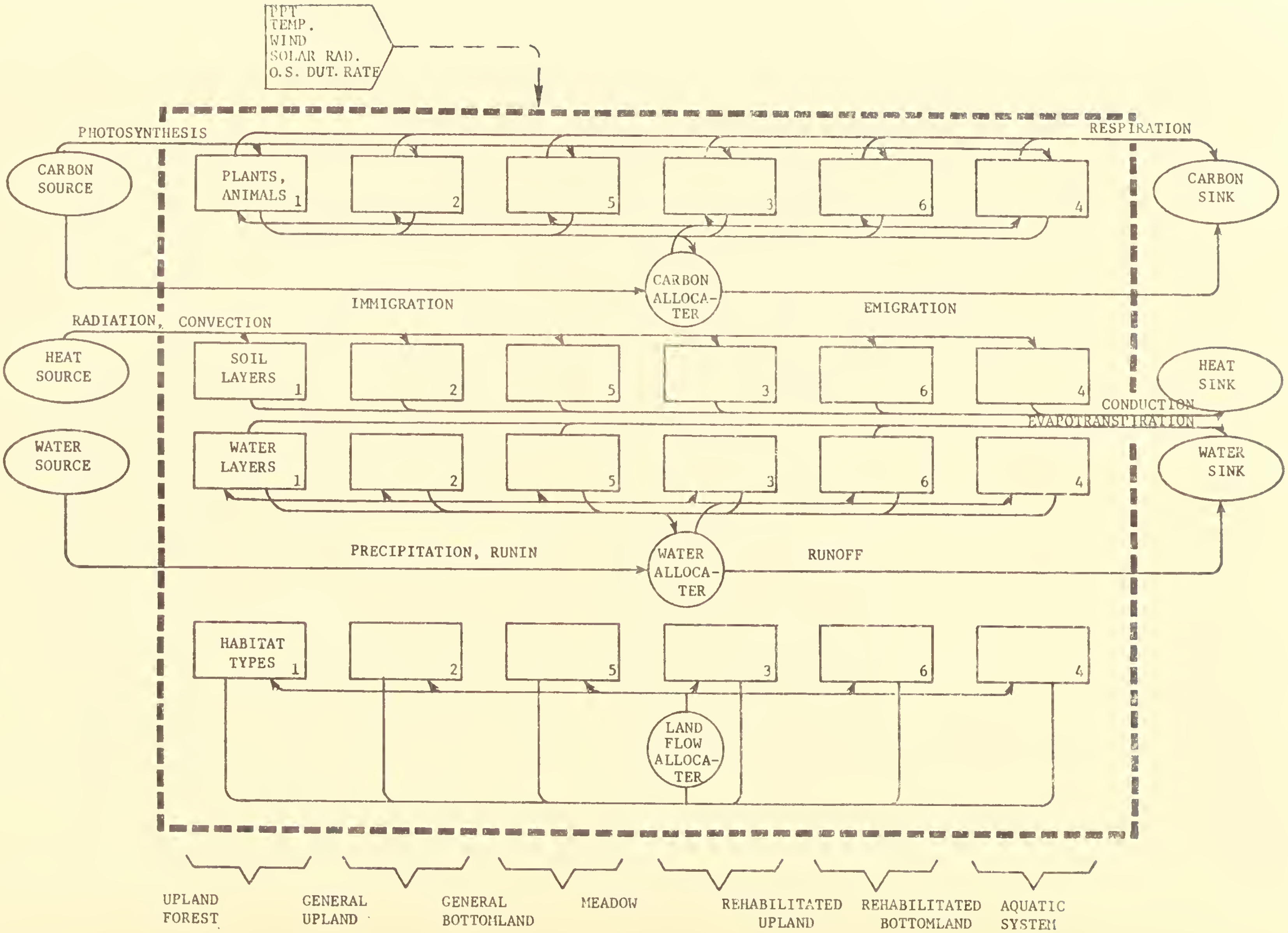


Figure C-1 A SIMPLIFIED CONCEPTUAL VIEW OF THE GENERAL TRACT C-b SYSTEM WITH CARBON, HEAT, AND WATER FLOWS DEFINED. DASHED BOUNDARY ENCLOSES THE SYSTEM. DRIVING VARIABLES, SOURCES, AND SINKS ARE EXTERNAL TO THE SYSTEM.

groundwater below ground.

Land area flows from one habitat to another are primarily related to development of rehabilitated lands, either in upland or bottomland sites. In the initial conceptualization the rehabilitated stands are assumed well established and thus are not divided into age classes.

Examination of Figure C-1 by experienced field biologists would lead to many suggestions for change to make the system more realistic. Similarly, if one attempted to mathematically model the conceptualization shown in Figure C-1, a rather empirical approach would have to be taken to predict flows. By subdividing some of the compartments into more functional operational units more mechanism would be introduced. However, economy of design is necessary if mathematical implementation of the model is ever undertaken. Yet this must be balanced by a need to associate most functional relationships with measurable processes for abiotic and biotic components of the ecosystem. Using these guidelines, one can subdivide each of the major compartments within the structure shown in Figure C-1 into that shown in Figure C-2.

There was only one compartment for plant-animal carbon in Figure C-1, but in Figure C-2 there are five plant compartments and one animal compartment. The five plant compartments compare to those in Figure 3-1: live shoots, live roots, standing dead, aboveground litter, and belowground litter. This conceptualization is sufficient for the five terrestrial habitats, but obviously it is unsuitable for the aquatic subsystem. Carbon flows into the live shoot system via photosynthesis and out of the plant subcomponents via respiration, decomposition, and herbivory. Flows into the animal population are via natality and immigration; flows out are via death, respiration, and emigration.

A simplified heat-flow submodel diagram is presented in the middle portion of Figure C-2. A heat source, representing the atmosphere, allows for heat flow into the top soil layer primarily by radiation and convection. Flow occurs between the upper and lower soil layer by conduction. Flow goes out of the top soil layer by reradiation and convection and out of the bottom soil layer into the parent material below via conduction.

Expansion of the water-flow submodel in the bottom portion of Figure C-2 requires developing four water compartments as a minimum whereas there was only one previously (compare Figure C-1 and C-2). The four compartments are surface water, top soil layer water, bottom soil layer water, and groundwater. In this conceptualization water flows into the system via precipitation or runin from surface water from an adjacent habitat. Depending upon temperature, this surface water compartment may hold either snow (for relatively long periods of time) or rain (for relatively

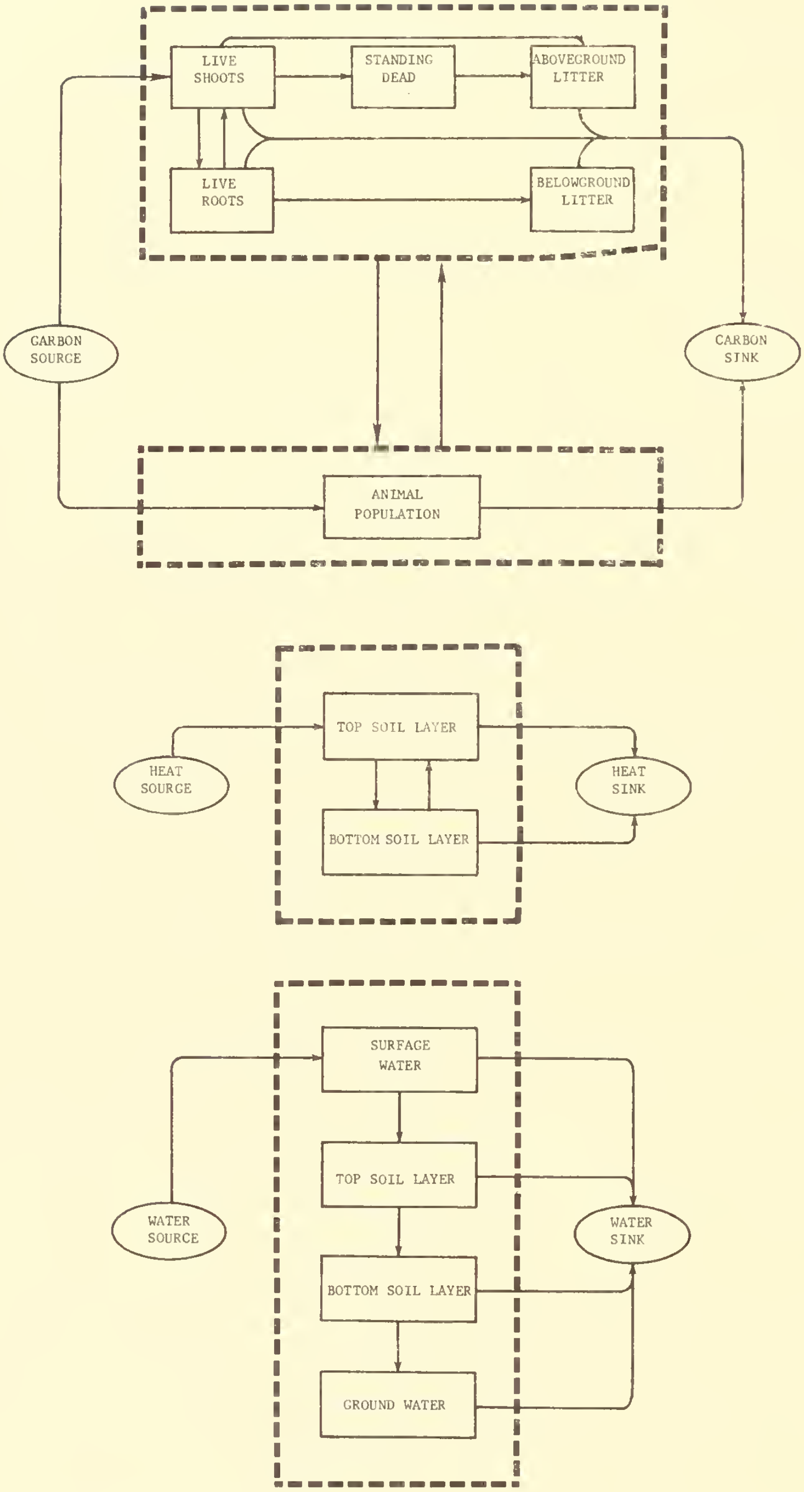


Figure C-2 A SIMPLIFIED CONCEPTUAL DIAGRAM OF FLOWS WITHIN THE CARBON, HEAT, AND WATER SUBSYSTEMS.

short periods of time). Depending upon temperature of the top soil layer and the amount of plant material available, infiltration may occur at varying rates into the top soil layer and thence into the bottom soil layer. Runoff may also occur to other habitat types. Some loss of water will occur by ablation from the snow surface or evaporation from the free-standing water. Once water is in the soil, there may be both evaporation and transpiration from the top soil layer, but only transpiration water loss would occur from the bottom soil layer. There is also percolation from the bottom soil layer into the groundwater layer. Movement of groundwater out accounts for loss to the water sink.

For this intermediate level of resolution, no further subdivision is required of the land area flow subsystem given previously.

C.3 Further Conceptualization

Figure C-2 now allows for a much more mechanistic level of detail than does Figure C-1 in conceptualizing the system. However, our field biologists still would find it difficult to provide parameters for estimating flow functions within the system. The conceptual model outlined in Figure C-2 is still highly aggregated in that only one type of plant and one type of animal are noted. In keeping with the initial aggregation and classification of system components, it is necessary to elaborate groups of plants and animals. Thus we can conceptualize the functional plant groups such as annual plants, perennial grasses, perennial forbs, shrubs, and trees in the terrestrial situation, and rooted plants and nonrooted plants in the aquatic situation. We can also subdivide animal groups, as has been done in the text.

To carry this diagrammatic conceptualization further would require dividing the animal categories into age-sex groupings. However, limited information from the field suggests this would be counterproductive at present. The final total system flow diagram appears in Chapter 5, Figure 5-6.

APPENDIX D

APPENDIX D INITIAL LISTS OF EFFECT GENERATORS AND RECEPTORS

D.1 Introduction

This appendix contains a complete list of the effect-receptor and effect-generator variables that were used to construct the preliminary effects matirx. The list was compiled utilizing the components and processes identified in Chapters 2 and 3 and the environmental perturbations associated with oil shale development. Table D-1 lists the effect generators, and Table D-2 contains the effect receptors.

Table D-1

EFFECT GENERATORS

DRIVING VARIABLES - (8)

- TIME - T
- PRECIPITATION - DPT
- AIR TEMPERATURE - DTA
- WIND - DWD
- SOLAR RADIATION - DRD
- PINYON - JUNIPER CLEARING - DCT
- LIVESTOCK GRAZING - DGR
- HUNTING AND RECREATION - DOL(9)

PERTURBATIONS - ATMOSPHERIC (25)

- SULFUR EMISSIONS DOL(1)
- SO_2
- H_2S
- NITROGEN EMISSIONS - DOL(2)
- NO
- NO_2
- NO_x
- OZONE AND OXIDANT EMISSIONS - DOL(3)
- FLUORINE EMISSIONS
- CO EMISSIONS - DOL(5)
- CH_4
- NMHC
- THC
- PARTICULATES AND AEROSOLS
- TRACE METAL CONTAMINANTS - DOL(4)
- ARSENIC

Table D-1

(CONTINUED)

- MERCURY
- SELENIUM
- WATER VAPOR EMISSIONS - DOL(6)
- STEAM EMISSIONS
- FOG
- ICE
- FUGITIVE DUST - DOL(7)
- ODOR
- NOISE AND ACTIVITY DISTURBANCE - DOL(8)

PERTURBATIONS - TERRESTRIAL (18)

- DISTURBED VEGETATION
- UNVEGETATED BARE AREAS
- TRANSMISSION LINES
- PIPELINES
- INCREASED ROAD KILLS
- ROADS AND PAVED SURFACES
- UNPAVED ROADS
- BARRIERS (FENCES, CULVERTS)
- LANDSLIDES
- CHANGES IN CONTOUR
- EROSION
- GROUND SUBSIDENCE
- COMPACTION
- MIXED SOIL PROFILE
- ALTERED HUMUS CONTENT

Table D-1

(CONTINUED)

- ALTERED SURFACE CHEMICAL COMPOSITION
- ALTERED SUBSURFACE CHEMICAL COMPOSITION
- SHRINK/SWELL CLAYS
- LANDFILLS

PERTURBATIONS - AQUATIC (14)

- PEAK FLOWS (FLASH FLOODING)
- SURFACE RUNOFF
- SEDIMENTATION
- DOWNSTREAM FLOW ALTERATIONS
- ALTERED STREAM CHANNESL
- ALTERED SURFACE DRAINAGE PATTERNS
- WATER TABLE ALTERATIONS
- ALTERED AQUIFERS
- IMPOUNDMENTS
- SEEPAGE
- EVAPORATION
- ALTERED GROUNDWATER CHEMICAL COMPOSITION
- ALTERED GROUNDWATER FLOW SYSTEMS
- ALTERED WATER QUALITY

SYSTEM STATE - PLANT (15)

- LIVE SHOOTS - CVS
- LIVE ROOTS - CVR
- STANDING DEAD - CVD
- ABOVE GROUND LITTER - CLA
- BELOW GROUND LITTER - CLB

Table D-1

(CONTINUED)

UPLAND FOREST AREA - ACR(1)

UPLAND NONFOREST AREA - ACR(2)

GENERAL BOTTOMLAND AREA - ACR(3)

MEADOW AREA - ACR(4)

UPLAND RECOVERY STAGE 1 - ACR(5)

UPLAND RECOVERY STAGE 2 - ACR(6)

UPLAND RECOVERY STAGE 3 - ACR(7)

BOTTOMLAND RECOVERY STAGE 1 - ACR(8)

BOTTOMLAND RECOVERY STAGE 2 - ACR(9)

BOTTOMLAND RECOVERY STAGE 3 - ACR(10)

SYSTEM STATE -ANIMAL (2)

TERRESTRIAL ANIMAL NUMBERS - PAN

TERRESTRIAL ANIMAL WEIGHTS - GAN

SYSTEM STATE - ABIOTIC (7)

TOP LAYER HEAT - HST

BOTTOM LAYER HEAT - HSB

TOPSOIL WATER - WTS

BOTTOMSOIL WATER - WBS

GROUNDWATER LAYER - WGR

AQUATIC TOP LAYER HEAT - HAT

AQUATIC BOTTOM LAYER HEAT - HAB

SYSTEM STATE - AQUATIC (12)

AQUATIC VERTEBRATE NUMBERS- PAV

AQUATIC INVERTEBRATE NUMBERS - PAI

Table D-1

(CONTINUED)

AQUATIC VERTEBRATE WEIGHT - GAV

AQUATIC INVERTEBRATE WEIGHT - GAI

AQUATIC ROOTED PLANTS - CAR

AQUATIC NONROOTED PLANTS - CAN

AQUATIC DETRITUS - CAD

SURFACE WATER - WST

AQUATIC SURFACE LAYER (ICE) - WAI

AQUATIC WATER - WAW

POND AREA - ACR(11)

STREAM AREA - ACR(12)

Table D-2

EFFECT RECEPTORS

ABIOTIC PROCESSES (35)

RADIATION - FTRAD

RERADIATION - FTRER

CONVECTION IN - FTCOI

CONVECTION OUT - FTCOO

CONDUCTION UP - FTCOU

CONDUCTION DOWN - FTCOD

CONDUCTION DOWN - FTCDO

RADIATION - FARAD

RERADIATION - FARER

CONVECTION IN - FACOI

CONVECTION OUT - FACOO

CONDUCTION UP - FACOU

CONDUCTION DOWN - FACOD

CONDUCTION DOWN - FACDO

PRECIPITATION - FTPPT

EVAPORATION SURFACE - FTEVS

EVAPORATION TOPSOIL - FTEVU

PRECIPITATION - FAPPT

EVAPORATION FROZEN - FAEVS

EVAPORATION WATER - FAEVW

MELTING (AQUATIC) - FASNI

MELTING INFILTRATION - FTSNI

INTERFLOW INFILTRATION - FTINE

PERCOLATION - FTPER

SURFACE WATER RUNIN - FIWRI

Table D-2

(CONTINUED)

SURFACE WATER RUNOUT - FIWRO

RUNOFF

STREAMFLOW - FASTR

SPRINGFLOW - FTGRV

FLOODING - FIFLD

GROUNDWATER FLOW IN - FIGWI

GROUNDWATER FLOW OUT - FIGWO

LITTER FLOW IN - FILRI

LITTER FLOW OUT - FILRO

WEATHERING (GEOLOGIC)

BIOTIC PROCESSES - PLANT (24)

GERMINATION & PHENOLOGY

NUTRIENT UPTAKE

TRANSLOCATION UP -FTTRS

TRANSLOCATION DOWN - FTTRR

PHOTOSYNTHESIS - FTPHO

SHOOT RESPIRATION - FTSHR

TRANSPIRATION, TOPSOIL - FTTRU

TRANSPIRATION, LOWER - FTTRL

SHOOT DEATH - FTSHD

SHOOT GRAZING - FTGRS

SHOOT SHATTERING - FTSHS

ROOT RESPIRATION - FTROR

ROOT DEATH - FTROD

ROOT GRAZING - FTGRR

Table D-2

(CONTINUED)

- DEAD GRAZING - FTGRD
- ABOVEGROUND LITTER GRAZING - FTGRA
- BELOWGROUND LITTER GRAZING - FTGRB
- DEAD SHATTERING - FTDES
- DEFORESTATION - FIDEF
- REHABILITATION - FIHRB
- STAND ESTABLISHMENT - FISTD
- INTERCEPTION OF PRECIPITATION *
- ABOVEGROUND DECOMPOSITION - FTABD
- BELOWGROUND DECOMPOSITION - FTBED

BIOTIC PROCESSES - ANIMAL (13)

- NATALITY - FTNAT
- MORTALITY - FTMOR
- GROWTH - FIGRO
- RESPIRATION - FTRES
- REPRODUCTION *
- IMMIGRATION - FTIMM
- EMIGRATION - FTEMI
- ANIMAL TRANSFER TO - FITRI
- ANIMAL TRANSFER OUT - FITRO
- PREDATION *
- FOOD SELECTION, TERRESTRIAL *
- EXCRETION INPUT - FTEXC
- DEAD ANIMAL INPUT - FIDED

BIOTIC PROCESSES - AQUATIC (25)

- PHOTOSYNTHESIS, ROOTED - FAPHR
- PHOTOSYNTHESIS, NONROOTED - FAPHN

Table D-2

(CONTINUED)

RESPIRATION ROOTED PLANTS - FARPR

DEATH ROOTED PLANTS - FASDR

GRAZING ROOTED PLANTS - FAGRR

RESPIRATION NONROOTED PLANTS - FARPN

DEATH NONROOTED PLANTS - FASDN

GRAZING NONROOTED PLANTS - FAGRN

TRANSPIRATION - FATRW

NATALITY VERTEBRATE AQUATIC - FANTV

GROWTH VERTEBRATE - FAGRV

RESPIRATION VERTEBRATE - FARSV

MORTALITY VERTEBRATE - FAMRV

NATALITY INVERTEBRATE - FANTI

GROWTH INVERTEBRATE - FAGRI

RESPIRATION INVERTEBRATE - FARSI

MORTALITY INVERTEBRATE - FAMRI

REPRODUCTION (AQUATIC BIOTA)

PREDATION

FOOD SELECTION, AQUATIC

EXCRETION INPUT - FAEXC

DEAD ANIMAL INPUT - FADED

DETRITUS DECOMPOSITION - FADEC

GRAZING DETRITUS - FAGRD

AQUATIC PLANT GROWTH

COMPONENTS - ABIOTIC (9)

AIR QUALITY *

AIR TEMPERATURE *

Table D-2

(CONTINUED)

- PRECIPITATION
- RELATIVE HUMIDITY
- WATER QUALITY
- SOIL PERMEABILITY/ WATERHOLDING CAPACITY
- SOIL MOISTURE
- SOIL CHEMISTRY AND pH
- SOIL TEMPERATURE

COMPONENTS - BIOTIC (6)

- INDICATOR SPECIES (AUTOTROPHS)
- PLANT TISSUE
- INDICATOR SPECIES (HETEROTROPHS)
- ANIMAL TISSUE
- GENERAL HABITAT
- LITTER AND DETRITUS

INDICES (2)

- DIVERSITY INDICES
- COMMUNITY COMPOSITION

APPENDIX E

APPENDIX E SUGGESTIONS FOR BUILDING A MATHEMATICAL MODEL TO SIMULATE ENVIRONMENTAL SYSTEM DYNAMICS ON TRACT C-b

E.1 Introduction

The conceptual model of an ecosystem can be used to translate qualitative concepts into quantitative mathematical formulations through a system of differential equations that are analagous to the real-world ecosystem.

E.2 A General Dynamic Model

Figure E-1 shows a simplified view of the state variable formulation for our ecosystem model. We define a vector of state variables and a vector of driving variables, e.g., those listed in Chapter 2. The derivatives or changes in the state variables are identified by a vector, x. In a simplified version of the state variable formulation we can represent the flows and interrelationships among the variables in the terms of matrices A and B. The overall formulation, in the simplest case, can be represented by a set of coupled first-order, linear, constant-coefficient differential equations, but this would represent only a first step along that route. In reality, it would be more reasonable to implement a system of nonlinear differential equations for the series of variables and flows defined in the graphic conceptual model herein.

Considering the type of structure outlined in Figure E-1 for a mathematical model, the need for the subscripts and acronyms becomes apparent. Within the framework of the system of differential or difference equations outlined in Figure E-1, nearly 500 coupled equations would be required, with the system being driven by 15 driving variables.

E.3 Implementation

Implementation of the large-scale system flow diagram of Figure 5-6 into mathematical equation systems for purposes of simulation poses several difficulties. The overall size of the model is a problem unless large-memory, high-speed digital computers are used. To simulate the system requires a simulation language or structure with special properties. These include the ability to use subscripted state variables so that flow

Figure E-1 A simplified state-variable mathematical formulation for a dynamic model of the C-b system. State variables are x_i, driving variables are z_i, coefficient matrices are a_{ij} and b_{ij}, and system differential equations are $\dot{x}_i$.

$$x = \begin{bmatrix} \text{cattle numbers} \\ \text{deer numbers} \\ \text{insectivorous bird numbers} \\ \cdot \\ \cdot \\ \cdot \\ \text{water layer volume} \\ \text{aquatic surface area} \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \cdot \\ \cdot \\ \cdot \\ x_{55} \\ x_{56} \end{bmatrix}$$

$$z = \begin{bmatrix} \text{precipitation} \\ \text{air temperature} \\ \text{wind} \\ \cdot \\ \cdot \\ \cdot \\ \text{noise} \\ \text{human activity} \end{bmatrix} = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ \cdot \\ \cdot \\ \cdot \\ z_{14} \\ z_{15} \end{bmatrix}$$

$$A = \begin{bmatrix} a_{1,1} & a_{1,2} & a_{1,3} & \cdot & \cdot & \cdot & a_{1,56} \\ a_{2,1} & a_{2,2} & a_{2,3} & \cdot & \cdot & \cdot & a_{2,56} \\ a_{3,1} & a_{3,2} & a_{3,3} & \cdot & \cdot & \cdot & a_{3,56} \\ \cdot & & & & & & \\ \cdot & & & & & & \\ \cdot & & & & & & \\ a_{56,1} & a_{56,2} & a_{56,3} & \cdot & \cdot & \cdot & a_{56,56} \end{bmatrix}$$

$$B = \begin{bmatrix} b_{1,1} & b_{1,2} & b_{1,3} & \cdot & \cdot & \cdot & b_{1,15} \\ b_{2,1} & b_{2,2} & b_{2,3} & \cdot & \cdot & \cdot & b_{2,15} \\ b_{3,1} & b_{3,2} & b_{3,3} & \cdot & \cdot & \cdot & b_{3,15} \\ \cdot & & & & & & \\ \cdot & & & & & & \\ \cdot & & & & & & \\ b_{56,1} & b_{56,2} & b_{56,3} & \cdot & \cdot & \cdot & b_{56,15} \end{bmatrix}$$

$$\dot{x} = Ax + Bz$$

expressions do not have to be written repeatedly for each of the 11 terrestrial systems, the aquatic system, the ten animal types, or the five plant types. Also, utilizing different time-steps in the solution of the model makes the task much more economical. Thus, for example, land area changes might take place only on a yearly basis, population changes of animals and weight changes of animals might be calculated on weely or fortnightly bases, water flows might be calculated on a daily basis, heat flows, might be weekly, and plant carbon biomass might be daily. If all flows had to be calculated on a daily basis for the minimum time-step given above, the amount of computational time would rise drastically. Having a simulation model structure such that different time steps could be utilized would greatly reduce computational time.

Once the basic "normal" flows have been determined, however, several approaches are available for modeling the effects of multiple factors on the processes that control the flows. These might be briefly names as follows (i) "a maximum reduction approach," (ii) a "nominal modification approach," (iii) a "law of the minimum approach," (iv) a "complex algorithm approach" such as used in an optimization modeling approach, and (v) empirically derived predictive statistical relationships. Of the possibilities, we probably do not have enough information to use the complex algorithm approach except in a few instances of specific kinds of flows. For example, in the grazing flow, we can look at the grazing process as an optimization problem where a given herbivore tries to select among the plant categories available to him in such a way as to maximize his preference ratings for these categories at a given time. But even there, we may not have sufficient information for the range of herbivores we have visualized in our conceptual model.

The maximum reduction approach to combining variables in the mental or numerical flow calculation procedure requires (i) selecting a maximum flow rate and (ii) reducing that maximum flow rate according to how far each of the affecting variables is from its optimal value. Thus for the relational diagrams (Figures 5-8 through 5-20) the ordinate would be scaled 0 to 1. The flow then is calculated by multiplying the maximal rate by a series of factors, each of the range 0 to 1, representing how close or how far each of the affecting factors is from its optimal level. Little information is available as to the maximal flow rates for the flows visualized in the Tract C-b system. This information could be derived by extensive review and analysis of available literature and information from this and related systems. In some cases, these rates can be derived by inspecting the overall couplings in the initial flow diagram (Figure 5-5) and making analyses as to how the donor and receiver compartments vary and thus calculating what flow rates might occur. The maximal reduction approach, however, is a simplified straightforward procedure for calculating flows and has much to offer should the conceptual model ever be implemented numerically.

The nominal modification approach is similar to the maximum reduction approach; a given flow is set and then is modified by a series of multiplying factors. This incorporates then the effects of several factors simultaneously on the flow. Instead of setting the maximal rate of flow, the "nominal" or average rate of flow is set. This nominal rate is based on observation or measurements from field conditions. In contrast, the maximal rate may be derived often under laboratory conditions. The nominal rate then is multiplied by factors that vary from 0 up to much greater than 1 in some instances. The value 1 of the factor then refers to the nominal value or effect of that variable on the flow. A value less than 1 means that the variable of concern is at less than nominal value; a value of greater than 1 means the variable is at more than nominal value. This approach has much to offer in that it is a straightforward, methodical way of presenting flow calculations. Often, nominal values can be measured or observed in the field.

The law of the minimum approach follows an ecological adage based on Liebig's Law of the Minimum which states that several factors may affect a process or variable but the one in minimum supply has an overriding effect. Thus, using the relational diagrams of Figures 5-8 through 5-20, the ordinate would be scaled in actual flow rate values, e.g., units of $g\ m^{-2} d^{-1}$ or some other flow value rather than a relative scaling value of 0 to 1 as in the case of the maximum reduction approach. A separate decision is required, however, to determine which variable is the controlling variable at any given time a flow is mentally or numerically calculated. Few field or laboratory data are available for the Tract C-b on which to make this latter decision. Thus the law of the minimum approach seems to be less applicable to ecological situations similar to the Tract C-b than are the previous two approaches.

The empirical additive prediction equation approach requires a statistically derived function to be developed to predict the flow from a series of driving and state variables. This function can be calculated based on time-series data such as those derived from the field situation (see Table 6-1 and Figures 2-1 through 2-9). In such empirical equations the dependent variable is the flow and the independent variables are the values at each day or time step of the driving variables and the state variables of the system. These multiple regression statistical equations could be first-order, linear or they could be second-order including power and cross-product terms. Using this approach requires a large data base for values of flows, values of driving variables, and values of state variables collected simultaneously over a wide range of conditions. These conditions are not fully met for the present Tract C-b data, but proxy equations could be derived from analysis of data from related situations for certain processes. These proxy equations then would be the starting point towards numerically implementing a flow model.

APPENDIX F

USER'S REFERENCE TO VOLUME V OF THE FINAL BASELINE REPORT, TRACT C-b

(Refer to Supplementary Envelope)

Form 1279-3
(June 1984)

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